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Science Focus

FOOD FOR THOUGHT

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TRUST ALGORITHMS

Inside the mind of
A FORENSIC SCIENTIST

COVID-19
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FOOD

BUSTED

WHY NEARLY EVERYTHING YOU'VE BEEN TOLD ABOUT FOOD IS WRONG

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Hurricanes
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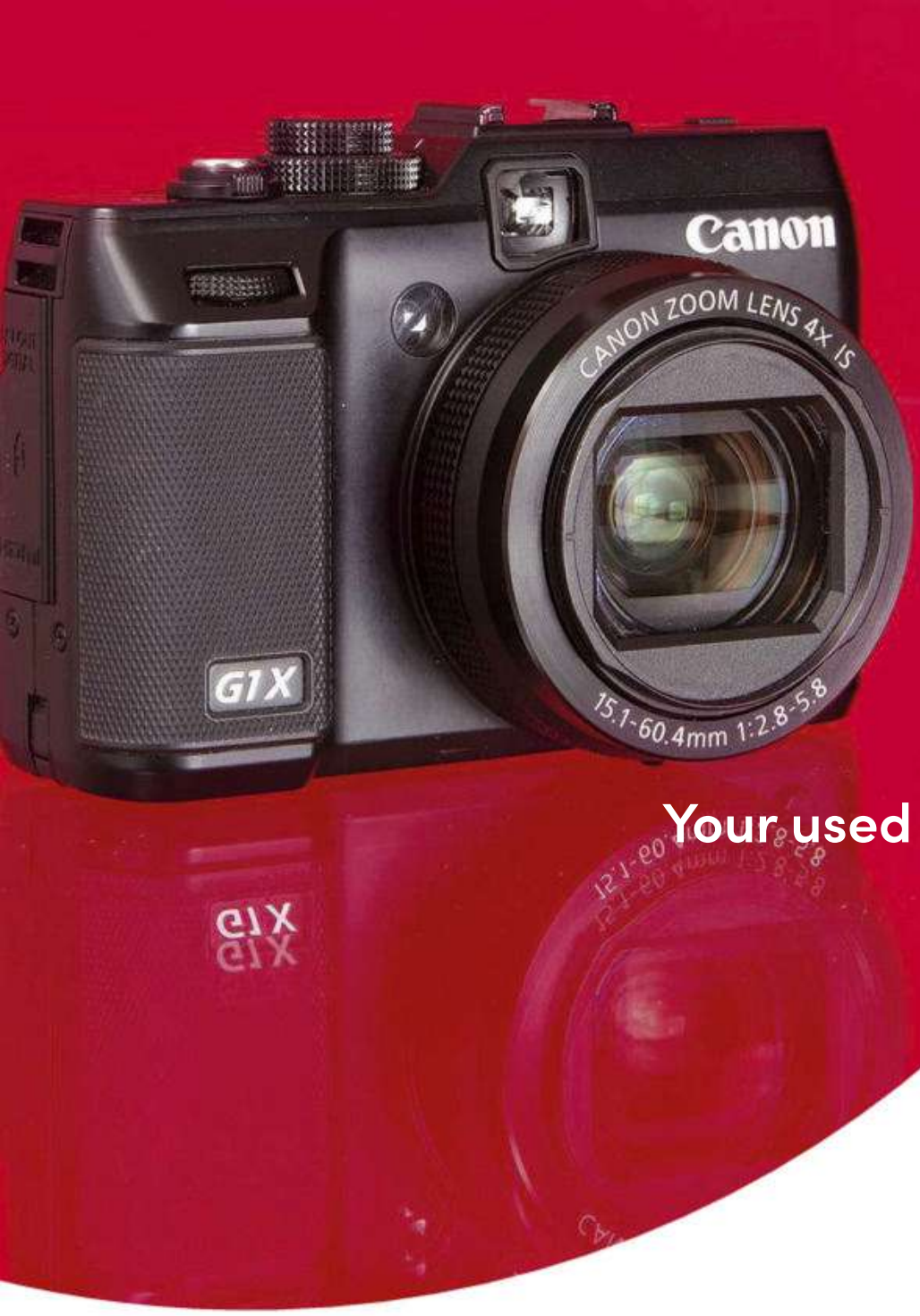

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FROM THE EDITOR

Food occupies much of my thoughts, maybe too much. Growing up in an Indian home, the kitchen was the place to be. The rest of the day simply orbited dinner, and the preparation of it. Sweets and treats materialised as the seasons changed, and Diwali – which usually falls around about this time – meant an influx of fried goodies rich in butter, sugar and salt. It's not surprising then that an Asian heritage also brings with it a higher risk of heart disease, and I've got a nagging worry that my heart could benefit from a few changes to my diet.

The trouble is, working on this magazine has made me deeply cynical. This is mostly useful. But when it comes to health, the constant influx of new food heroes and villains leaves my head spinning. I've lost track of whether or not I should eat breakfast, drink coffee or buy eggs. And don't get me started on counting calories. I once did a bit of digging to try and figure out how many calories my home-cooked meals contained, and I ended up in the strange world of fitness forums, where people quibble over the calorific differences between a cold and hot potato.

It seems that the food world and I both need some sane advice when it comes to how to eat healthily, and that's exactly what Prof Tim Spector, a genetic epidemiologist and food writer, has served up on p56. Head there now for a fad-free, refreshing read on the science of what we put in our bodies.

Enjoy the issue!

Daniel Bennett, Editor

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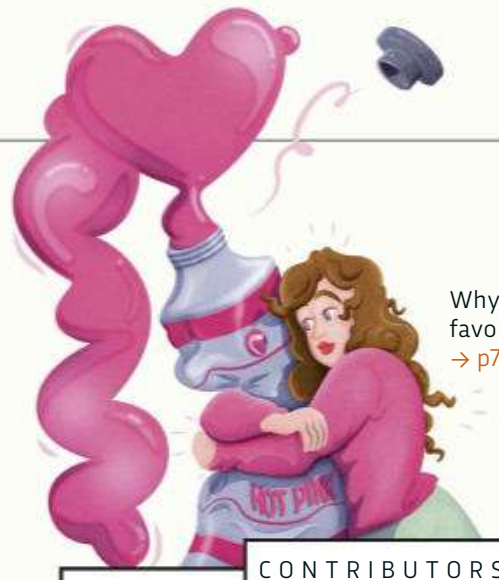

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ON THE BBC THIS MONTH...

Autumnwatch 2020
This year's *Autumnwatch* brings its presenters together virtually. Viewers can expect to see live footage of nature on the doorstep of Chris Packham's home in the New Forest and Michaela Strachan's home in the Tentsmuir Forest.
BBC Two
From 27 October

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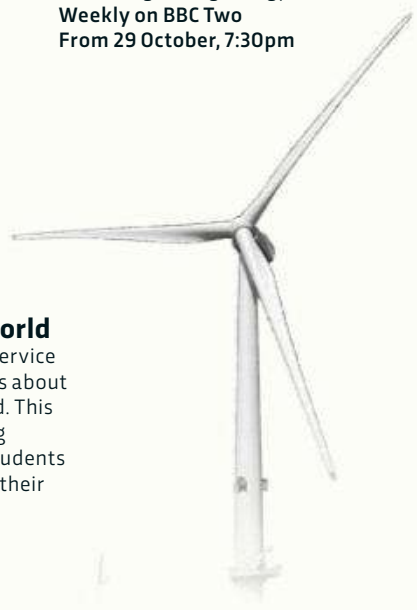
Each week the BBC World Service meets people with big ideas about how to transform the world. This month includes an inspiring episode with high school students who've solved problems in their local community.
BBC World Service
Tuesdays, 8am



Powering Britain
This four-episode series looks at energy production across the UK, meeting the people at nuclear power stations, gas fields and windfarms to see how they cope with our growing energy demands.
Weekly on BBC Two
From 29 October, 7:30pm

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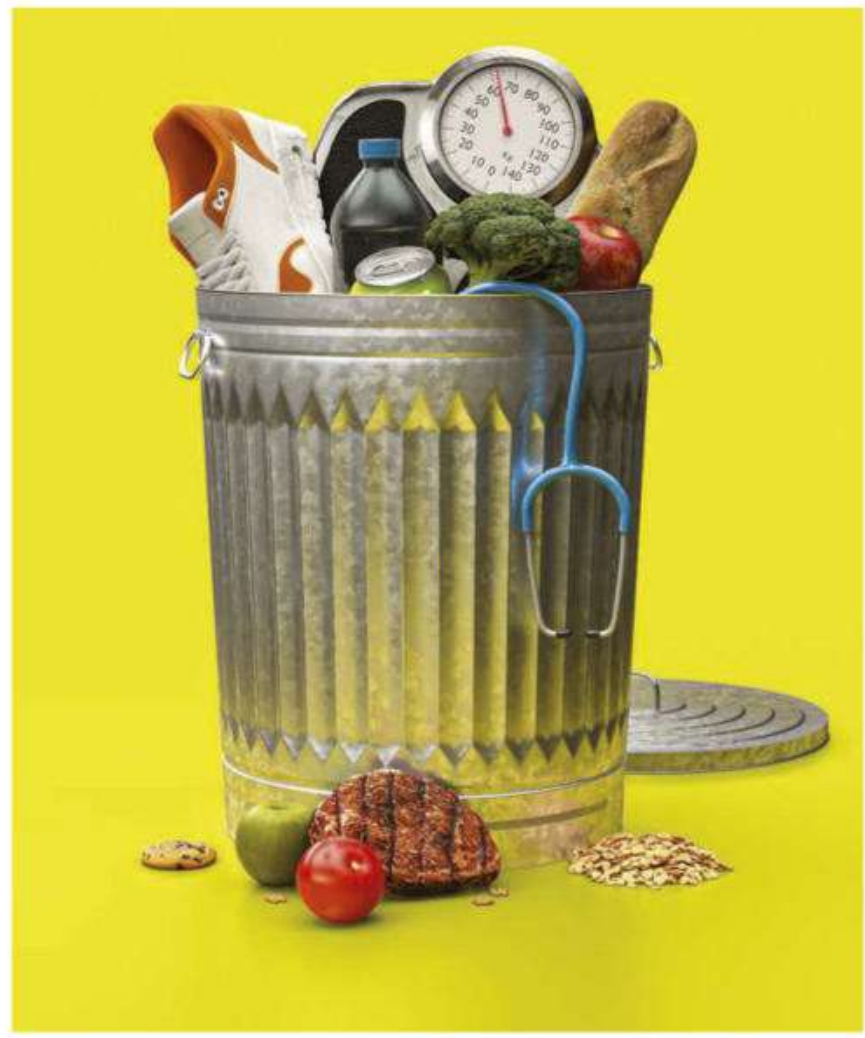

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"WE ARE BETTER ABLE TO COPE WITH STRESS WHEN WE EXPERIENCE MORE SUPPORT. AND ONLINE, WE HAVE MORE CONNECTIONS WHO ARE WILLING TO GIVE US A BOOST"

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SPECIAL ISSUE

OCEANS: THE INCREDIBLE SECRETS OF OUR BLUE PLANET
In this special edition, the experts from *BBC Science Focus* don their diving kit and take the plunge into the depths of the oceans, to reveal more about the incredible world beneath the waves.
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EYE OPENER

Forest floors

CHENGDU, CHINA

Construction of the Qiyi City Forest Garden was completed last year, but only a few residents have moved in. Without the careful attention of green-fingered families, the plants have overgrown.

"These are tropical specimens, selected for pollution absorption and to be noise-reducing through their dense growth," explains Michael Perry, horticulturist and TV presenter. "It would have been better to choose dwarf plants, or to make sure plants are clipped and maintained. In such a humid climate this needs to be once a week too, not a few times a year!"

The humid climate has led to another problem with the vertical garden city: it is now infested with mosquitoes. "Mosquitoes love water. The balcony containers hold onto a lot of moisture and the area's monsoons will not have helped. As the plants are overgrown, there's a lot of shade for mosquitoes to hide in, too," says Perry. "It's become a rather perfect habitat for them."

AFP / SHUTTERSTOCK

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EYE OPENER

Surf's up!

YEPPOON, AUSTRALIA

This 3.6-hectare lake in northeast Australia is the testing facility for Surf Lakes – a company that's aiming to replicate the experience of ocean waves and provide surfers with a place to hone their craft.

In the middle of the lake is a gigantic, steampunk-esque plunger, driven by compressed air, which pushes in and out of the water every six seconds. Each pulse of the 1,400-tonne behemoth creates concentric waves that radiate outwards. The lake's bottom has been designed to give different types of waves in different areas, from gently rolling waves for beginners to hollow, two-metre-high waves for the pros. "The faster the lake becomes shallow, the more violently the wave rears up and breaks," says Kit Sidwell, the project's lead mechanical engineer.

This particular facility isn't open to the public, but the company hopes to open its first commercial site, probably in Australia, within the next couple of years.

SURF LAKES TECHNOLOGY

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EYE OPENER

Spot the difference

JUPITER

Jupiter is famous for its iconic storm, the Great Red Spot. It has been raging since at least 1830 and currently measures about 15,700km across – large enough to swallow Earth. But this image, taken by the Hubble Space Telescope in August, suggests that a new storm is brewing in Jupiter's northern latitudes, and can be seen here as a pale, stretched-out blob on the upper left of the planet.

"This new storm is a convective event – like a giant thunderstorm – in Jupiter's high-speed wind jet," says NASA planetary scientist Amy Simon. "They are likely generated by heat released far below the clouds' tops that causes a plume of warm rising atmosphere that condenses into bright white clouds."

Another notable feature is Oval BA, aka Red Spot Jr, located just below the Great Red Spot. It has been slowly fading to white after appearing red in 2006, but this new image suggests that its core is starting to darken once again.

NASA/ESA

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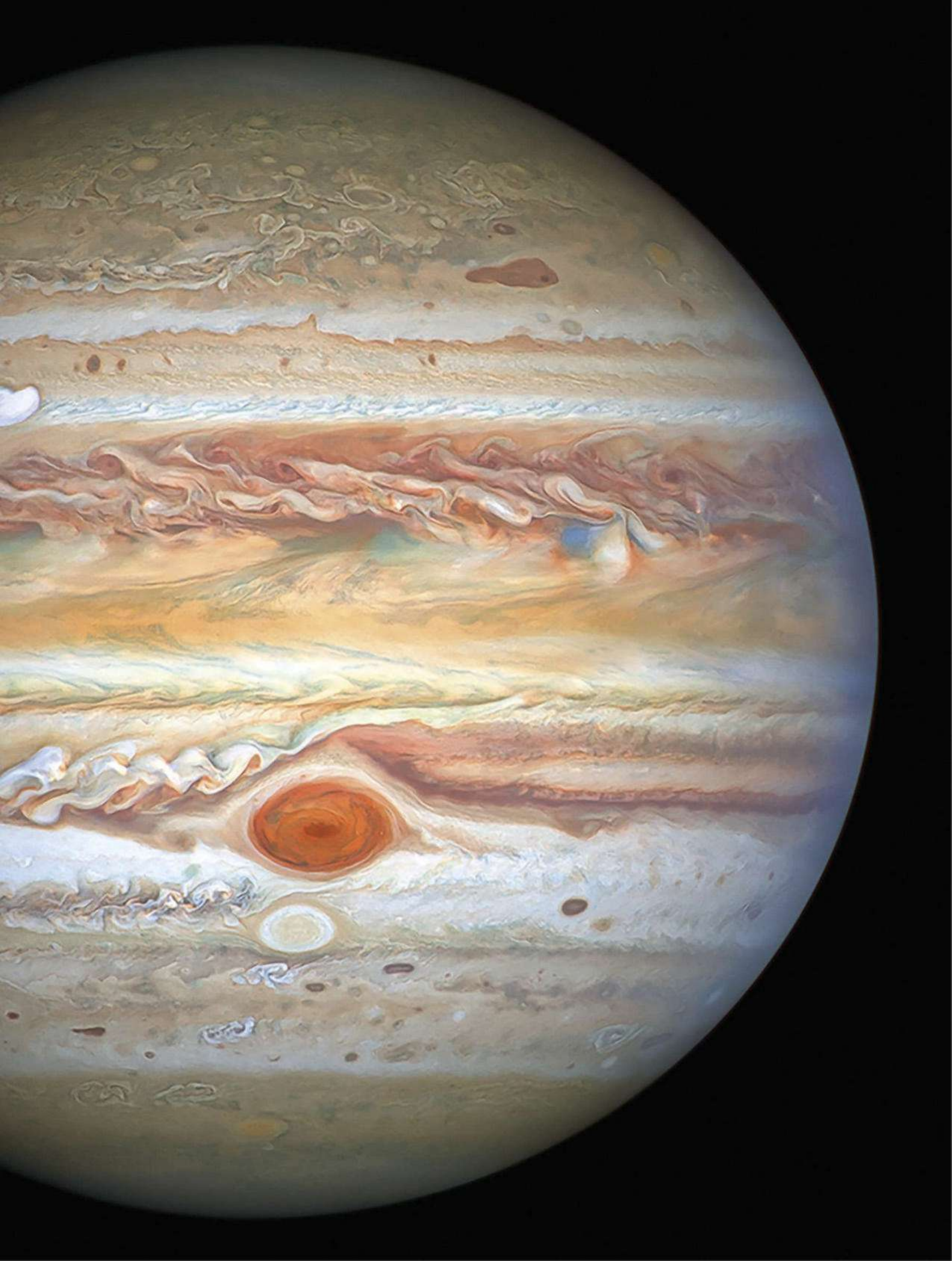

CONVERSATION

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND *BBC SCIENCE FOCUS*

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LETTER OF THE MONTH

Ask a glassmaker

In response to the question 'Is it possible to recycle plastics an infinite number of times?' (Summer, p85) you wrote that glass and aluminium don't degrade during recycling. This is not the case with glass. If you took all the bottles made in a container factory and kept feeding them back into the furnace, the glass would gradually become more and more viscous, and eventually the machines would be unable to produce any more bottles. I once was faced with the problem of running out of glass in a tank furnace, which was never emptied but topped up with 'batch' (raw materials) weekly. As we kept gathering the glass it became more difficult to work with and the quality worsened. The resulting products then cracked during cooling because the glass had absorbed so much silica and alumina from the furnace lining. So, yes, you can keep recycling glass, and glassmakers usually recycle waste glass from manufacturing process but you need to add new raw material. You can't recycle indefinitely.

Alastair MacIntosh

WRITE IN AND WIN!

The writer of next issue's *Letter Of The Month* wins a **Papalook HD video webcam**. Even in low light conditions it still offers good clarity, while its omnidirectional microphone filters out background noise for purer sound. It's easy to set up via USB and is compatible with Mac, Windows, Chrome and Android. **papalook.com**

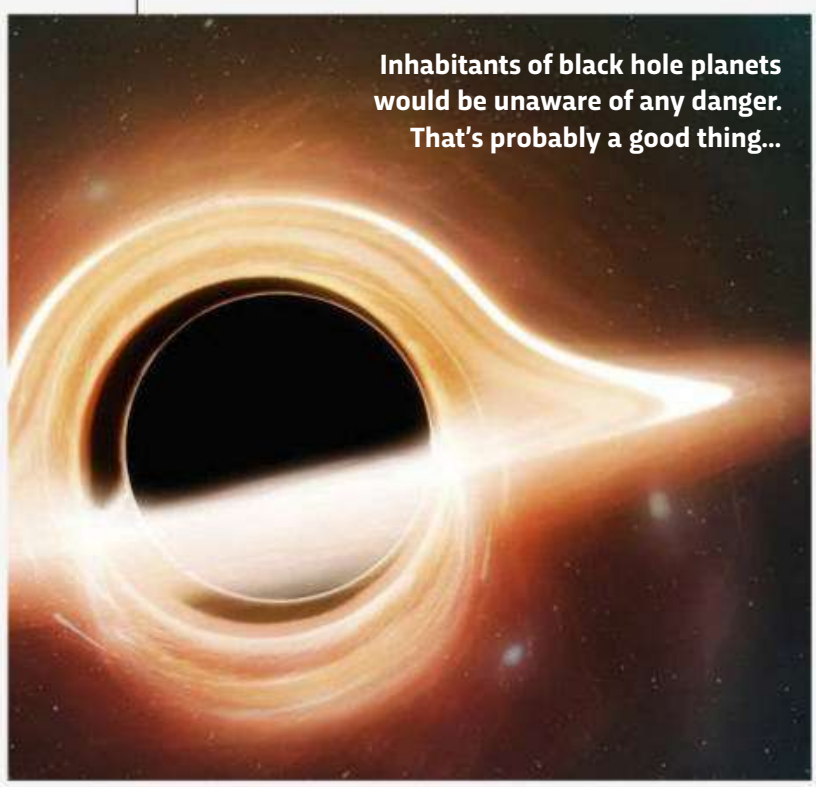
Alien life

While I was fascinated to read the article 'Can life exist around a black hole?' (August, p54) it was rather too focused on the planets, rather than life. What sort of life might exist on such planets? What would it be like to live in the shadow of such a monster?

Danny Herbert

Putting aside the fact that second-guessing the mindset of hypothetical aliens is *always* a stretch, my hunch is that there aren't intelligent civilisations inhabiting black hole planets. The gravity of the black hole is so extreme that time is severely dilated, meaning only 14 million years have passed there since the Big Bang. Multicellular life didn't appear on Earth until at least a billion years after its formation.

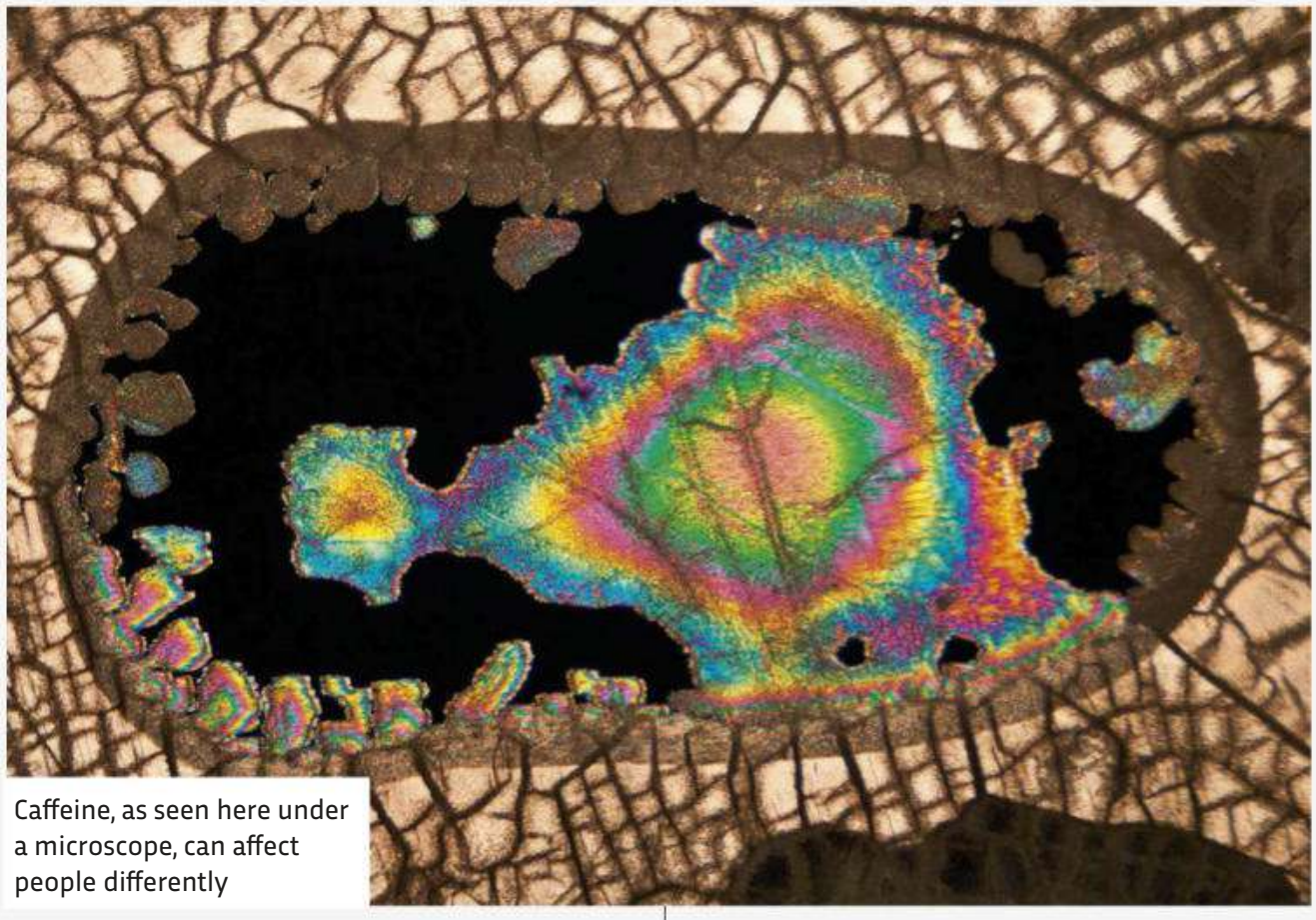
To make matters even worse, the sky on a black hole planet is devoid of stars and other planets. Without them, inhabitants are unlikely to have figured out Kepler's laws of planetary motion, which are required to weigh the black hole and know how massive it



Inhabitants of black hole planets would be unaware of any danger. That's probably a good thing...

"TO BE ABLE TO HARNESS THAT POWER OF SCIENCE TO MAKE THINGS BETTER, TO ENSURE THAT THE RIGHT PEOPLE ARE PUT ON THE RIGHT SIDE OF THE BARS, IS INCREDIBLY IMPORTANT"

DAME PROF SUE BLACK, P68



Caffeine, as seen here under a microscope, can affect people differently

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is. From their perspective it looks just like the Sun does to us. Ignorance is bliss.
Colin Stuart, *astronomy writer*

If only they could talk

I was tickled to see a smiling toothbrush in the *Innovations* pages of the August issue (p44). You're quite right comparing it to Douglas Adams's sighing doors. However, it did result in me trying to personify items around my house for the rest of the day (the things we do to avoid work).

I decided that my biscuit tin would 'tut tut' and look down at my belly when I removed the lid, my lawnmower would squint at finally seeing some daylight, and the settee would probably groan when I sat down. As for my games console, that would most definitely wink and say, 'come play me, come play me'... at least that's what I tell my wife.

Steve Shepherdson, *London*

In critique of caffeine

I read Dr Michael Mosley's piece 'In praise of caffeine' (September, p57) with interest, as I suffer from migraines that can be caused by caffeine. Because of this, I gave up caffeine over 15 years ago. Even decaf tea can set them off now as I am highly sensitive to it.

Caffeine has also given me heart palpitations in the past, which can take months to go away. I'd be interested to know why my experience is so different from Michael's.

Andy Goodwin, *Sussex*

There is clear evidence that some people are much more sensitive to the effects of caffeine than others, and some people break down caffeine faster than others.

I suspect you are both sensitive to caffeine and a slow metaboliser, which is just bad luck!

Dr Michael Mosley, *BBC Science Focus columnist*

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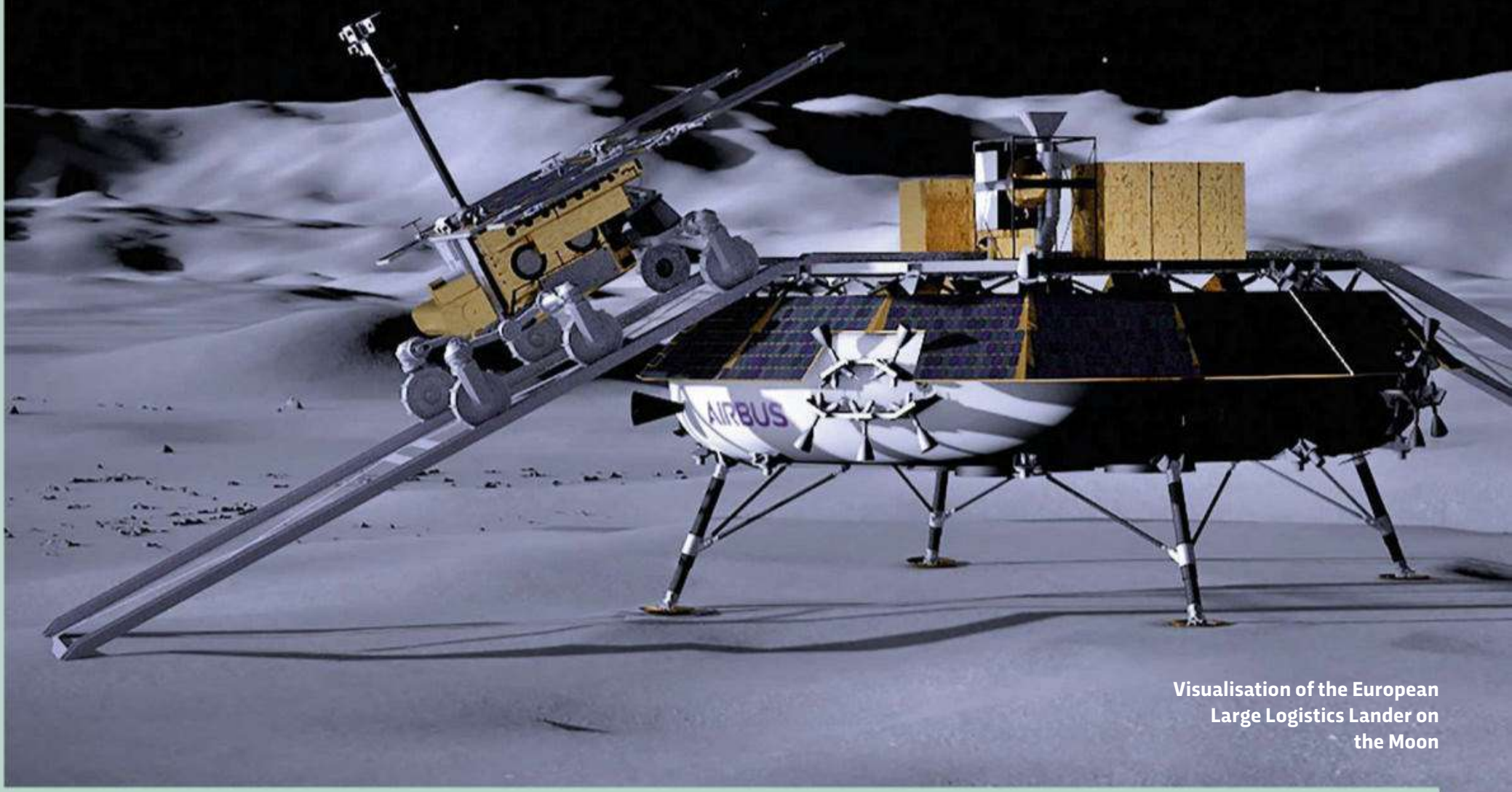
HEAR, HEAR
Scientists design hearing aid that costs less than £1 **p24**

DISCOVERIES

BOLD NEW PLANS FOR THE FUTURE OF SPACE EXPLORATION

The plans include landing the first woman on the lunar surface, establishing a space station in orbit around the Moon, and returning samples of Martian rock to Earth



NASA/GSFC

Visualisation of the European Large Logistics Lander on the Moon

Neanderthal DNA may increase severity of COVID-19 Genes from our ancient cousins seem to be linked to a serious response to the coronavirus p26 **Touching issue** Prior to the pandemic, more than half of us wanted more physical contact p31

LEFT Testing of the Space Launch System's booster

BELOW The new class of astronauts may travel to the Moon and Mars as part of the Artemis programme

The European Space Agency (ESA) has announced a multi-billion-euro investment to the robotic and human exploration of the Solar System. It represents a large expansion to the contribution that Europe is already making to Artemis, the NASA programme to land the first woman and the next man on the Moon during 2024. The new contracts are worth a total of €2.9bn (£2.6bn approx) and are designed to help Artemis become a long-term sustainable exploration of the Moon by astronauts, and take Mars exploration to the next level by returning Martian rocks to Earth for analysis.

ESA's involvement in these programmes has been made possible thanks to funding decisions taken in Seville, Spain, last year by the science ministers of ESA's 22 member states. At the end of two days of negotiations, they endorsed the most ambitious plan to date for the future of ESA and the whole European space sector.

"The decisions taken in Seville were fundamental. They basically set us with a programme for this coming decade," said David Parker, ESA's director of human and robotic exploration.

Europe is already involved in NASA's Orion spacecraft, which will transport astronauts to the Moon and, potentially, other destinations in the Solar System. The European Service Module supplies the Orion crew capsule with air, water and electricity. It keeps the spacecraft on course and at the right temperature. ESA will be supplying at least four service modules, with the potential for another two after that. They will help deliver astronauts to the lunar gateway, a space station in orbit around the Moon.

FLY ME TO THE MOON

ESA is committed to delivering two modules to the gateway. The first is the International Habitat (I-Hab). It will be a pressurised living area with docking ports for visiting vehicles, supplied by Thales Alenia Space, Italy, and launched in 2025.

The second is ESPRIT, European Systems Providing Refuelling Infrastructure and Telecommunications. It will function as a communications relay between astronauts on the surface of the Moon and Earth, and will take additional fuel to the gateway to keep it operational well into the 2030s. It will also feature a spectacular viewing port so that astronauts can gaze at the surface of the Moon. The communications part will launch in 2022, while the main refuelling module and viewing ports will launch in 2027. Before then, NASA and ESA plan a lot of lunar activity.

In September, NASA published its plan for the first phase of Artemis programme, which culminates in the human Moon landing of 2024.

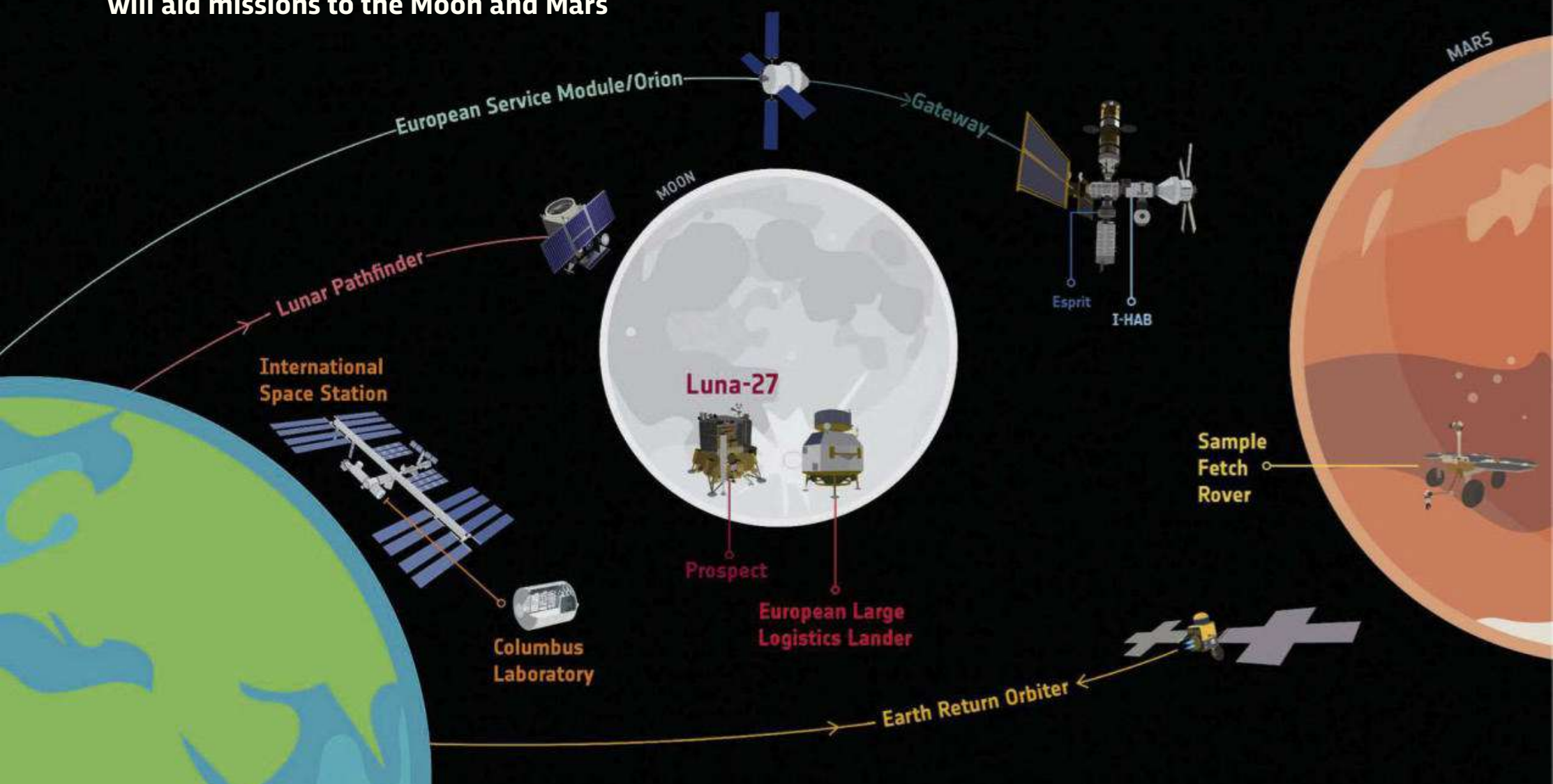
The first mission, known as Artemis I, is on track for 2021. NASA's new rocket, the Space Launch System (SLS), will take the Orion capsule around the far side of the Moon for a test without astronauts. Artemis II will fly with astronauts in 2023, more or less repeating its predecessor's journey.

During this time, NASA, ESA and other international partners will be landing robotic equipment on the lunar surface to conduct preparatory experiments. The Prospect instrument is a robotic drill and a miniature laboratory that will fly on the Russian Luna-27 mission, slated for launch in 2025. Built in Italy, it will study the soil near the lunar south pole, which contains water.

Artemis III is the mission that will take humans to the surface the Moon. This is the part of the mission with the most question marks about whether it will be ready in time. NASA has awarded contracts to three different industrial consortia to study possible designs for this spacecraft. But it will be a close-run thing to have it ready, tested and working by 2024. Whenever that mission lands humans on the Moon, ESA will support the activity by providing communications through the Lunar Pathfinder satellite. Built by Surrey Satellites Technology, UK, ESA will buy telecommunications services

EUROPE'S EXPLORATION

Thanks to more than €2bn of funding from ESA, these craft will aid missions to the Moon and Mars



GETTY IMAGES X2, ARIANNE P ORLA ILLUSTRATIONS: CATHAL DUANE

from them, effectively helping to fund the spacecraft.

ESA has also begun studying the European Large Logistics Lander (EL3) with the company Airbus, Germany. "We need a lunar transit van," said Parker, "Something that can land a tonne and a half of payload to support human exploration."

EL3 is just that. It's being designed to land anything from rovers to food and supplies, to science instruments, and equipment to extract lunar resources to make water and oxygen.

Up until now, it's been easy to think that NASA's plans to return to the Moon have been a largely solitary endeavour tinged with political motives that could evaporate if the White House changes hands in November. Now, the international contributions show how robust the programme is. Europe is the strongest partner, but others, such as Canada, Japan and Australia, are joining too. Also, the language in NASA's September announcement stresses the broad support for the programme.

"With bipartisan support from Congress, our 21st-Century push to the Moon is well within America's reach," said NASA administrator Jim Bridenstine. "As we've solidified more of our exploration plans in recent months, we've continued to refine our budget and architecture. We're going back to the Moon for scientific discovery, economic benefits, and inspiration for a new generation of explorers. As we build up a sustainable presence, we're also building momentum toward those first human steps on the Red Planet."

Before those human steps can be taken on Mars, more robotic ones will have to be made. And so contracts have now been announced for future Mars missions in which ESA and NASA will collaborate to bring back samples of the Red Planet to Earth by 2031.

NASA's Perseverance rover is currently en route to a February 2021 touchdown. In its exploration of Mars, it will cache interesting looking rock samples in collection tubes. ESA has now committed to two missions to help bring those tubes back to Earth. The Sample Fetch Rover will navigate autonomously, detect the tubes, pick them up and place them in a canister on a NASA-supplied Mars Ascent Vehicle. The Sample Fetch Rover will be supplied by Airbus, UK. Once the NASA vehicle reaches Mars orbit, it will release the sample canister, which will be captured by ESA's Earth Return Vehicle, which will bring them to Earth. This spacecraft will be supplied by Airbus, France.

As well as collecting invaluable geological samples, such a mission is also a prelude to human exploration. "Sample return is scientifically worth doing on its own merits, because bringing back pristine Mars material will transform our understanding of the Red Planet," said Parker, "But it's also kind of a scale model of an eventual human Mars mission." This is because the sample return requires multiple rocket launches, landings on and liftoffs from Mars. It's a great way to test the technology and techniques before scaling the vehicles up to human size.

"Some of us have been talking about this for 10 to 12 years. Having discussions, planning, and trying to keep the momentum going to the point where suddenly it becomes a real program," said Parker, "Now this is a real programme. And Europe is right in the middle of it."

—

by **DR STUART CLARK**

Stuart is an astronomy writer.

BIOLOGY

Stop and think before buying a flat-faced dog, the Royal Veterinary College warns

Chihuahuas, pugs, French bulldogs and British bulldogs are more likely to suffer from health problems than other breeds

The popularity of many flat-faced dog breeds such as French bulldogs has risen dramatically in recent years, despite regular assertions that they are prone to many health issues including breathing problems and sore eyes.

However, there has been limited reliable evidence on the wider general health of flat-faced – or brachycephalic – dogs across the spread of common disorders, when compared to other dog breeds.

Now, a study led by the Royal Veterinary College's VetCompass programme, which examined the overall health of a random sample of 4,169 flat-faced dogs compared to 18,079 other dogs that attended veterinary practices in the UK, has confirmed that brachycephalic dogs are more likely to suffer from a range of health disorders.

Out of the 30 common disorders found across both groups, flat-faced dogs have a higher risk of eight of them (other dogs had a higher risk of two of them). Flat-faced dogs were more than eight times more likely to suffer from the painful eye disease corneal ulceration, three-and-a-half times more likely to suffer from heart murmurs, and three times more likely to suffer from umbilical hernias.

"The message here is that it is perfectly natural to love the character and look of these breeds, but we need to think carefully about the lives that these dogs live," said Dr Dan O'Neill, senior lecturer at the Royal Veterinary College (RVC) and lead author of the study. "I appeal to anyone thinking of buying a flat-faced puppy to listen to the message from the Brachycephalic Working Group, which represents major UK breed clubs, charities, veterinary bodies and universities: 'Stop and think before buying a flat-faced dog.'"

French bulldogs, which have been bred since the 1800s, have short faces that can make breathing difficult

The findings support the general agreement by academics, UK breed clubs, veterinary organisations and welfare bodies that urgent intervention is needed to breed dogs with less extreme body shapes, the researchers say.

"We've put into place a number of crucial measures to monitor and improve brachycephalic health, and to provide the many responsible breeders with the tools they need to do the same, but this paper highlights there is still much work to be done," said Bill Lambert, head of health and welfare at the Kennel Club. "Collaborating with the RVC and supporting this research through the Kennel Club Charitable Trust provides an evidence base which enables ongoing identification of breed health-related priorities, and development of effective treatments for breed-specific health conditions, as well as breeding resources to produce healthier puppies in the future."

AVOCADO-MUNCHING HIPSTERS
Fear not, moustachioed social media influencers, it looks like the future of 'smashed avo' is safe and sound. A team at the University of Queensland has figured out a way to cryopreserve avocado shoots, potentially ensuring their future for generations.

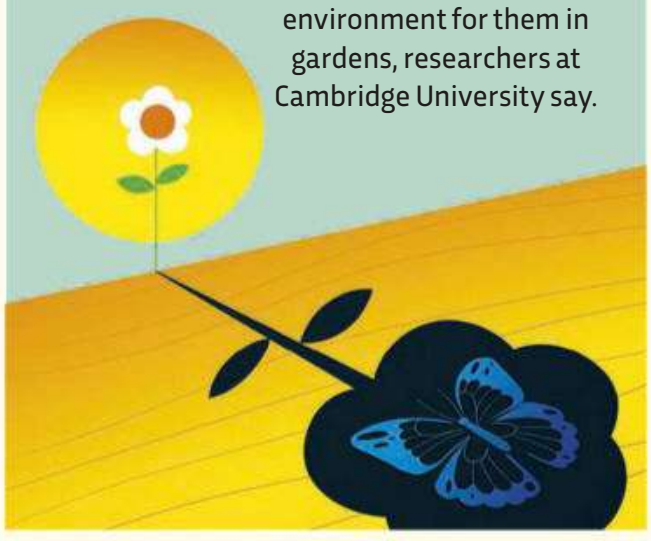
LAZY CAT OWNERS
Is your moggy always mewing for food? Try feeding them one large meal a day. A team at the University of Guelph, Ontario, found that eating just once a day can help cats control their appetites and help them to stay healthier. You may as well, they don't love you anyway.

Good month

Bad month

CURLING PLAYERS
A team at Korea University in Seoul have developed an AI-powered robot that is capable of defeating human players at the fascinating Olympic sport of curling. Even less reason to play it now then.

BUTTERFLIES
Two-thirds of the UK's butterfly species are in decline, thanks to habitat loss removing the 'microclimates' in which they live. Butterflies can't generate their own body heat and can struggle with changes in temperature. Help the little guys out by providing a varied environment for them in gardens, researchers at Cambridge University say.



GETTY IMAGES X2, ARIANNE PORLA ILLUSTRATIONS: CATHAL DUANE

Magawa shows off his PDSA gold medal

ZOOLOGY

Meet Magawa, the landmine-detecting rat who has been awarded a medal for bravery

Meet Magawa, the first rat to ever be awarded a PDSA gold medal. The five-year-old African giant pouched rat has found 39 landmines and 28 other potentially dangerous items of unexploded ordnance over the past four years, sniffing his way across 140,000 square metres of land – the equivalent of 20 football pitches.

He was born in Tanzania in November 2014 and completed nine months' of training at APOPO's HeroRAT Training and Research Center in Tanzania, where he learned how to detect the smell of explosives using his nose. He was then sent off to Siem Reap in Cambodia to get to work sniffing out landmines.

"APOPO's HeroRATs significantly speed up landmine detection, using their amazing sense of smell and excellent memory. We use clicker training to teach rats like Magawa to scratch at the ground above a landmine. During training they hear a 'click' and receive a tasty food reward for finding the correct target scent," said CEO of APOPO Christophe Cox. "Unlike metal detectors, the rats ignore scrap metal and only sniff out explosives, making them fast and efficient landmine detectors. This not only saves lives but returns much-needed safe land back to the communities as quickly and cost-effectively as possible. This in turn will allow the families living around the minefields to improve their livelihoods and get their lives back on track."

Cambodia estimates that between four and six million landmines were laid in the country during the bitter conflict that raged in the country in the 1970s and 1980s. To date, they have been responsible for more than 64,000 casualties.

The PDSA gold medal was launched in 2002, awarding bravery and devotion to duty for non-military animals, and is said to be the animal equivalent of the George Cross.

MARINE BIOLOGY

Megalodon truly was a monster shark

The megalodon made famous by the film *The Meg* was abnormally large compared to its relatives, a new study has found.

Megalodon stalked the world's oceans between 20 and 3.5 million years ago. It was around 15 metres in length – over three times longer than the average great white shark – and was probably one of the largest and most powerful predators ever to have lived. The ancient behemoth belongs to a diverse group of sharks called the lamniforms, which also includes the great white. Calculating the size of extinct lamniforms is often hampered by a lack of fossils, and most are estimated from the size of their teeth (tooth fossils are the most common because sharks continually shed their teeth, going through up to 40,000 in their lifetime). In fact, 'megalodon' comes from the Ancient Greek for 'big tooth'.

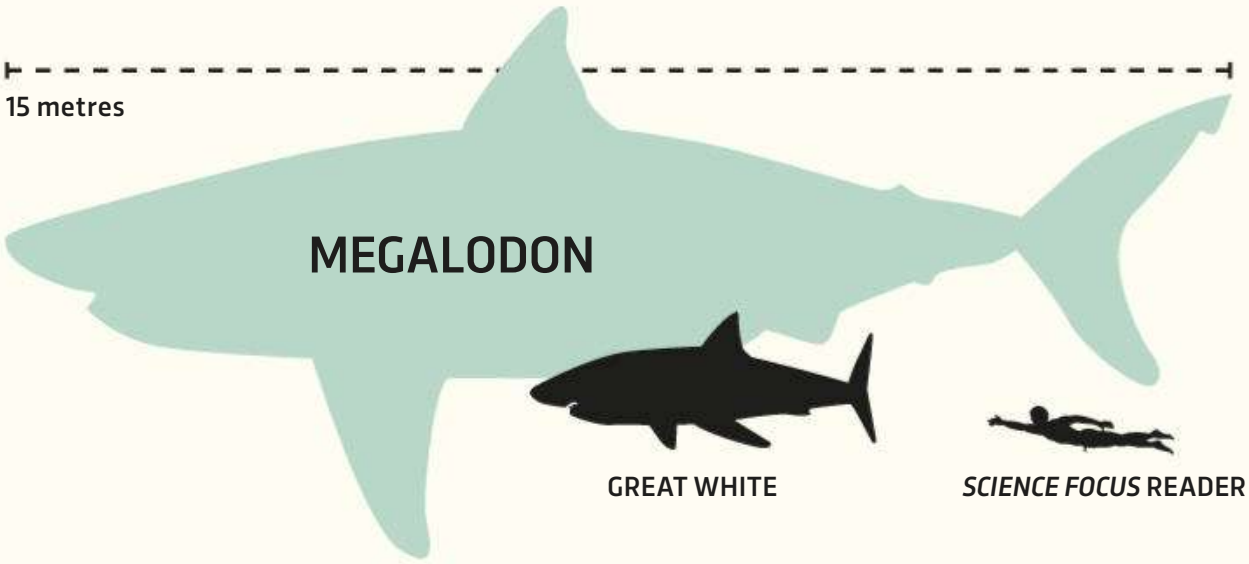
In this study, researchers led by Dr Kenshu Shimada, a palaeobiologist at DePaul University in Chicago, used measurements of modern-day lamniforms to create a mathematical equation linking the sharks' body lengths to the size of their teeth. This then allowed them to estimate the sizes of extinct lamniforms such as megalodon.

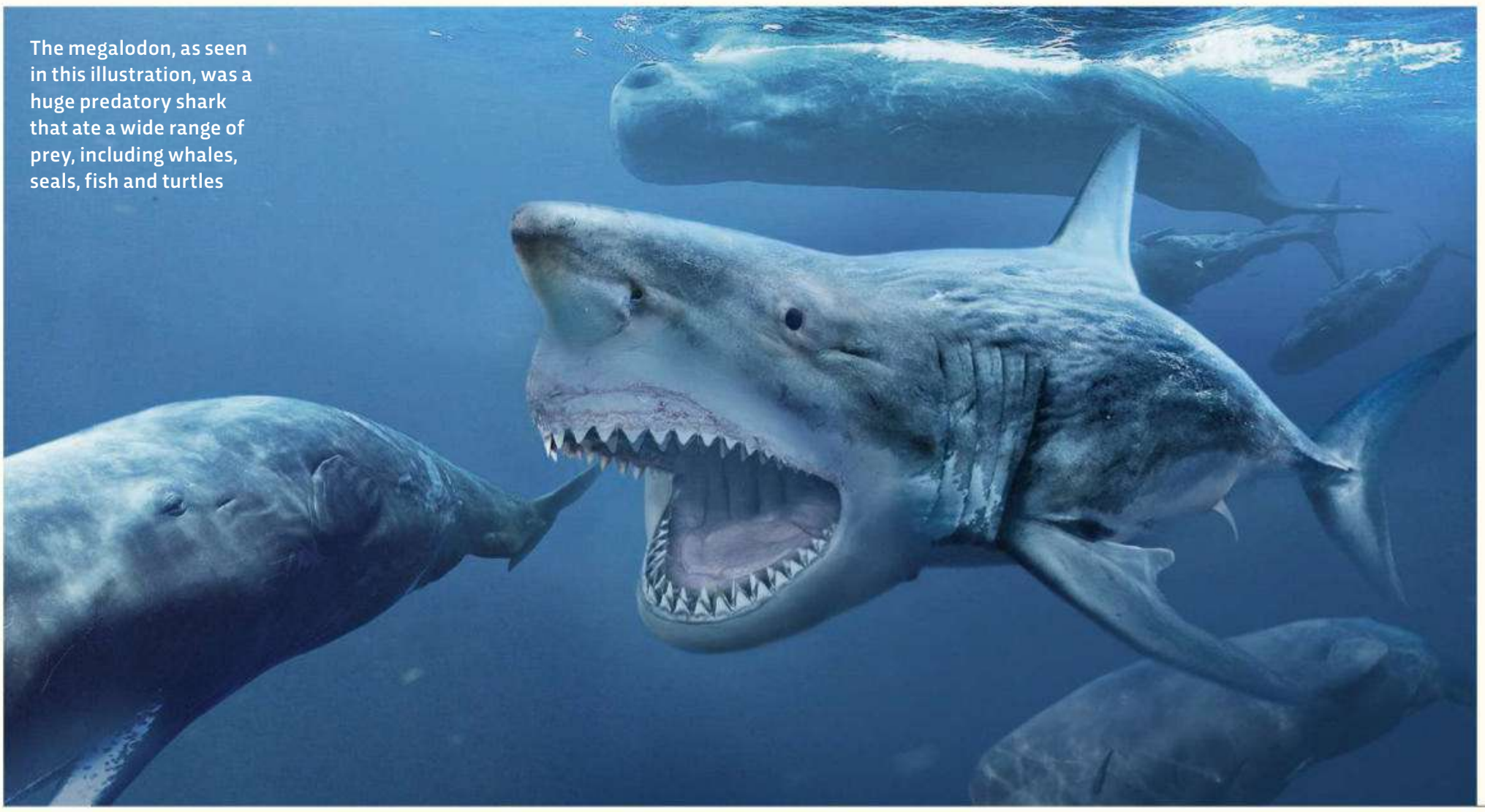
"This is compelling evidence for the truly exceptional size of megalodon," said co-author Dr Michael Griffiths at William Paterson University in Wayne, New Jersey.

They found that practically all of megalodon's fellow 'non-planktivorous' (non-plankton-eating) relatives had a size limit of around seven metres. Only a few plankton-eating sharks, such as the whale shark and the basking shark, would have come close to the megalodon in size.

Estimating the body sizes of extinct animals such as megalodon can help biologists to understand how they affected the lives and evolution of other animals around them.

"Lamniform sharks have represented major carnivores in oceans since the age of dinosaurs, so it is reasonable to assert that they must have played an important role in shaping the marine ecosystems we know today," said Shimada.





The megalodon, as seen in this illustration, was a huge predatory shark that ate a wide range of prey, including whales, seals, fish and turtles

'Martian' soil was combined with a chitin-based substance to create a building material, which the team used to make a tiny spaceman

MARS

A material based on bug shells could be perfect for building tools and shelters on Mars

With plans underway to revisit the lunar surface and eventually send a crewed mission to the Red Planet, future space exploration missions are likely to involve an extended stay. Any brave souls wishing to take on such an endeavour will need a reliable building material to construct tools and shelters.

Chitin, an organic polymer found in the cell walls of fungi and the exoskeletons of crustaceans and insects, could potentially be used as a building material by human settlers on Mars, according to a team led by Dr Javier Fernandez at Singapore University of Technology and Design. Early explorers are likely to consume insects as a source of protein, so chitin would be in ready supply.

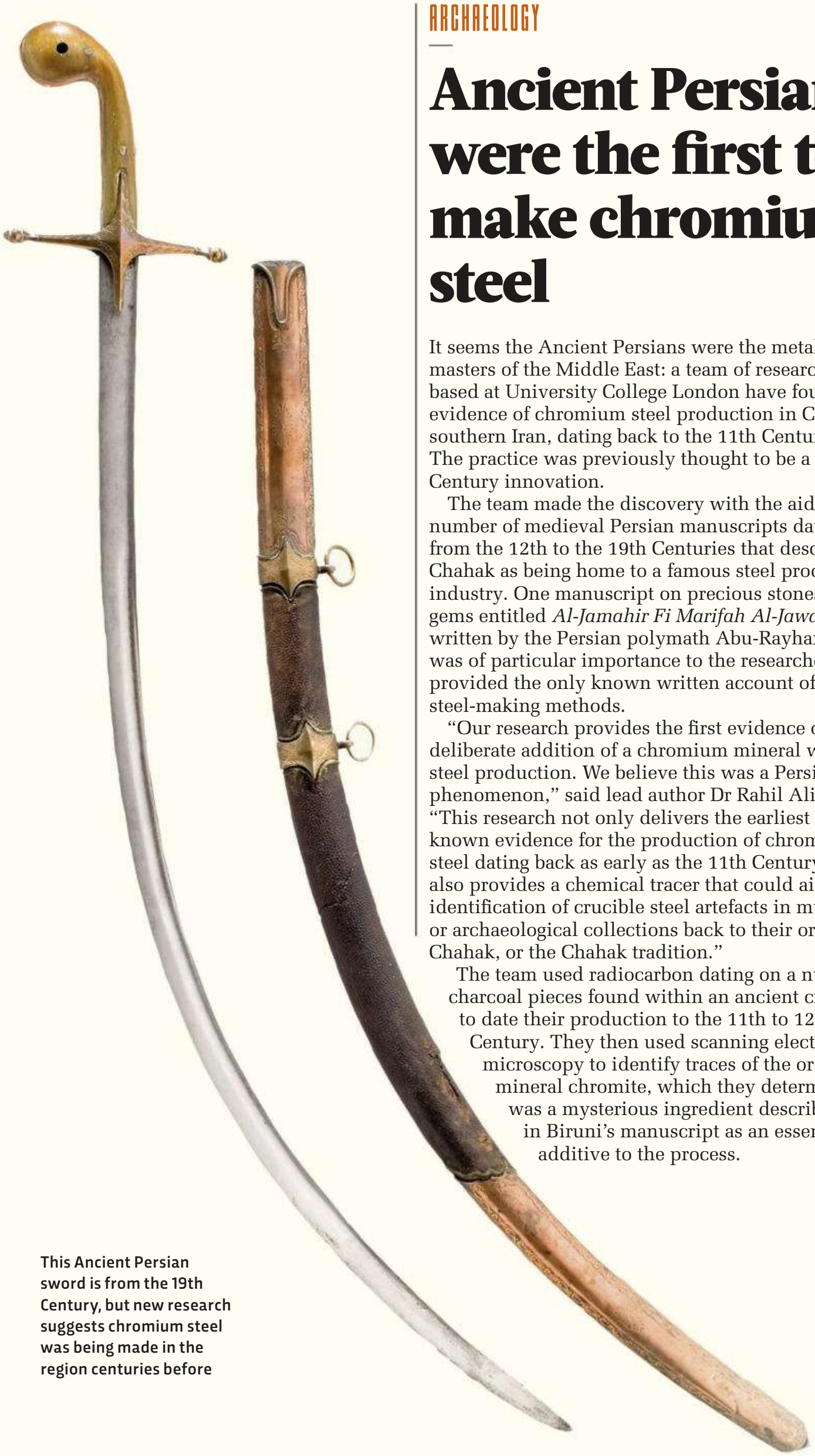
The team first created chitosan, which is made by treating chitin with an alkaline substance. The chitosan was then combined with a mineral that mimicked Martian soil to make a material that was used to construct a wrench and a model of a Mars habitat. The study showed that this material could allow the rapid manufacture of tools, and perhaps even rigid shelters.

"Bioinspired manufacturing and sustainable materials are not a substituting technology for synthetic polymers, but an enabling technology defining a new paradigm in manufacturing, and allowing us to do things that are unachievable by the synthetic counterparts," said Fernandez. "Here we have demonstrated that they are key not only for our sustainability on Earth but also for one of the next biggest

"It is the most efficient and scalable method to produce materials in a closed artificial ecosystem"

achievements of humanity: our transformation into an interplanetary species. The technology was originally developed to create circular ecosystems in urban environments, but due to its efficiency, it is also the most efficient and scalable method to produce materials in a closed artificial ecosystem in the extremely scarce environment of a lifeless planet or satellite."

SCIENCE PHOTO LIBRARY, JAVIER G FERNANDEZ



This Ancient Persian sword is from the 19th Century, but new research suggests chromium steel was being made in the region centuries before

ARCHAEOLOGY

Ancient Persians were the first to make chromium steel

It seems the Ancient Persians were the metal masters of the Middle East: a team of researchers based at University College London have found evidence of chromium steel production in Chahak, southern Iran, dating back to the 11th Century. The practice was previously thought to be a 20th-Century innovation.

The team made the discovery with the aid of a number of medieval Persian manuscripts dating from the 12th to the 19th Centuries that described Chahak as being home to a famous steel production industry. One manuscript on precious stones and gems entitled *Al-Jamahir Fi Marifah Al-Jawahir*, written by the Persian polymath Abu-Rayhan Biruni, was of particular importance to the researchers as it provided the only known written account of crucible steel-making methods.

"Our research provides the first evidence of the deliberate addition of a chromium mineral within steel production. We believe this was a Persian phenomenon," said lead author Dr Rahil Alipour. "This research not only delivers the earliest known evidence for the production of chromium steel dating back as early as the 11th Century, but also provides a chemical tracer that could aid the identification of crucible steel artefacts in museums or archaeological collections back to their origin in Chahak, or the Chahak tradition."

The team used radiocarbon dating on a number of charcoal pieces found within an ancient crucible to date their production to the 11th to 12th Century. They then used scanning electron microscopy to identify traces of the ore mineral chromite, which they determined was a mysterious ingredient described in Biruni's manuscript as an essential additive to the process.

In numbers

$23m

The cost (£17m approx) of a new space toilet designed by NASA, which is currently being tested on the ISS. It is smaller and lighter than current models, and better suited to female crew.

15 MINUTES

The amount of intense exercise that can help improve the memory and acquisition of new skills in healthy participants, a study at the University of Geneva has found.

90%

The proportion of UK households that recycle regularly, as found in a survey carried out by the Recycle Now campaign.

3H 42M

The duration of a Cuvier's beaked whale dive, as recorded by a team at Duke University. It's a new world record for the longest dive by a whale.

AKG IMAGES, CABI

Mould regrown from Fleming's frozen sample

Genome of Alexander Fleming's origin penicillin mould sequenced

The research may help in the fight against antibiotic resistance

Alexander Fleming famously discovered penicillin in one of science's greatest good luck stories in 1928 while working at St Mary's Hospital Medical School. The drug was produced by a mould in the genus *Penicillium* that accidentally started growing in a Petri dish he was using to study the bacteria *Staphylococcus aureus.* Much to his surprise, he noticed that the mould was suppressing the growth of the bacteria and so the first antibiotic was discovered.

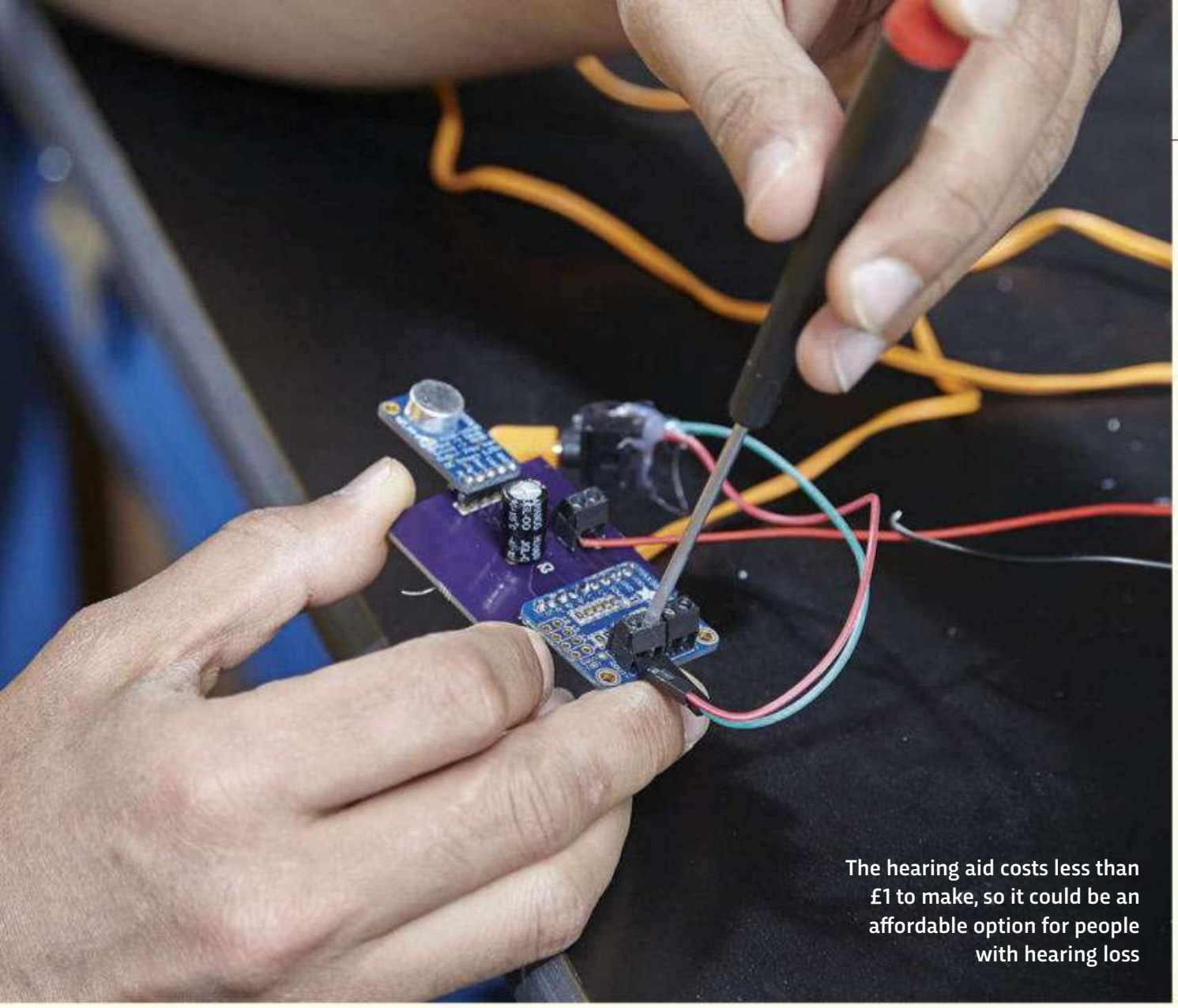
Now, researchers from Imperial College London, the Centre for Agriculture and Bioscience International (CABI) and the University of Oxford have sequenced the genome of Fleming's original *Penicillium* strain by re-growing it from a frozen sample kept at the culture collection at CABI.

"We originally set out to use Alexander Fleming's fungus for some different experiments, but we realised, to our surprise, that no one had sequenced the genome of this original *Penicillium*, despite its historical significance to the field," said lead researcher Prof Timothy Barraclough, from the Department of Life Sciences at Imperial and the Department of Zoology at Oxford.

Although Fleming's mould is famous as the original source of penicillin, industrial production moved to using fungus from cantaloupes in the US, in which the *Penicillium* samples were artificially selected for strains that produce higher volumes of penicillin.

By comparing the genomes of Fleming's strain to two strains currently used in the US, they discovered several key differences in the genes that code for penicillin-producing enzymes in the different fungi. The researchers say this shows that wild *Penicillium* in the UK and US evolved naturally to produce slightly different versions of these enzymes and could help in the fight against antibiotic resistance.

"Our research could help inspire novel solutions to combating antibiotic resistance. Industrial production of penicillin concentrated on the amount produced, and the steps used to artificially improve production led to changes in numbers of genes," said first author Ayush Pathak, from Imperial College London. "But it is possible that industrial methods might have missed some solutions for optimising penicillin design, and we can learn from natural responses to the evolution of antibiotic resistance."



The hearing aid costs less than £1 to make, so it could be an affordable option for people with hearing loss

TECHNOLOGY

New £1 hearing aid could help millions to hear more clearly

A new hearing aid that costs less than £1 to make has been developed by researchers at the Georgia Institute of Technology.

Even in the UK, around 11 million people are living with hearing loss, of whom 8 million are aged 60 or older. A hearing aid can help those who still have some hearing ability left, but are finding it hard to hear specific pitches of noise – such as doorbells or phones ringing – or struggle to pick out individual voices in a conversation. Hearing aids help because they can be tuned to boost sounds at certain frequencies, depending on the type of hearing loss a person has. For example, older adults tend to lose the ability to hear sounds at higher frequencies.

"I was born with hearing loss and didn't get hearing aids until I was in high school," said the paper's first author, Soham Sinha, a long-term user of hearing aid technology. "This project represented for me an opportunity to learn what I could do to help others who may be in the same situation as me but not have the resources to obtain hearing aids."

Instead of sitting behind the ear, the new, low-cost device hangs around the user's neck in a 3D-printed case. It uses a microphone to pick up sound, which is then sent to an amplifier to be enhanced.

"We used filters to shape the amplification, for example, to selectively amplify sounds above 1,000Hz," explained Dr Saad Bhamla, one of the study's authors. "This was done to match the typical age-related hearing loss acoustic profile, which shows loss of hearing in higher frequencies above 1,000Hz."

The work is still in its early stages, and it will be some time before the hearing aids can be produced commercially. But now that the initial steps have proven successful, the researchers say they are ready to take the next steps.

"We have shown that it is possible to build a hearing aid for less than the price of a cup of coffee," Bhamla said. "This is a first step, a platform technology, and we've shown that low cost doesn't have to mean low quality.

"We'll no longer be able to solder them ourselves in the lab. This is a labour of love for us, so we will miss that."

They did what?

Rats' teamwork skills put to the test

WHAT DID THEY DO?

A team from Eötvös Loránd University, Budapest, Hungary, placed a group of rats into a complex maze and had them search for a water reward positioned at just 1 of 16 endpoints in order to study their problem-solving behaviour when they operated as a 'team'. They dyed the rats' fur in differing bright colours so that they were able to easily track the movements of each individual animal.

WHY DID THEY DO THAT?

For decades, scientists have been placing single rats in a complex maze to search for a reward to deepen our understanding of navigation, memory and learning. Little is known about how they explore as a group, despite rats being highly social animals.

WHAT DID THEY FIND?

The team found that the rats performed better in groups by striking a balance between exploring by themselves and following others. The researchers say that algorithms based on the rats' movements could be used to help autonomous robots explore complex underground environments.

CRAIG BROMLEY, GETTY IMAGES ILLUSTRATIONS: CATHAL DUANE

HEALTH

COVID-19 is making its way into our nightmares, a study of lockdown dreams has found

A study of sleep and dreams carried out by researchers based in Helsinki, Finland has found that anxiety surrounding coronavirus features in more than half of our nightmares.

The team sourced sleep and stress data from 4,000 people during the sixth week of the COVID-19 lockdown in Finland. Nearly 800 of the contributors also supplied information about the content of their dreams.

The researchers then transcribed the content of the dreams from Finnish into English word lists, before feeding the resulting data into an AI algorithm, which scanned for frequently appearing word associations. They then used a computer program to build so-called 'dream clusters' from the various elements to identify 33 specific themes.

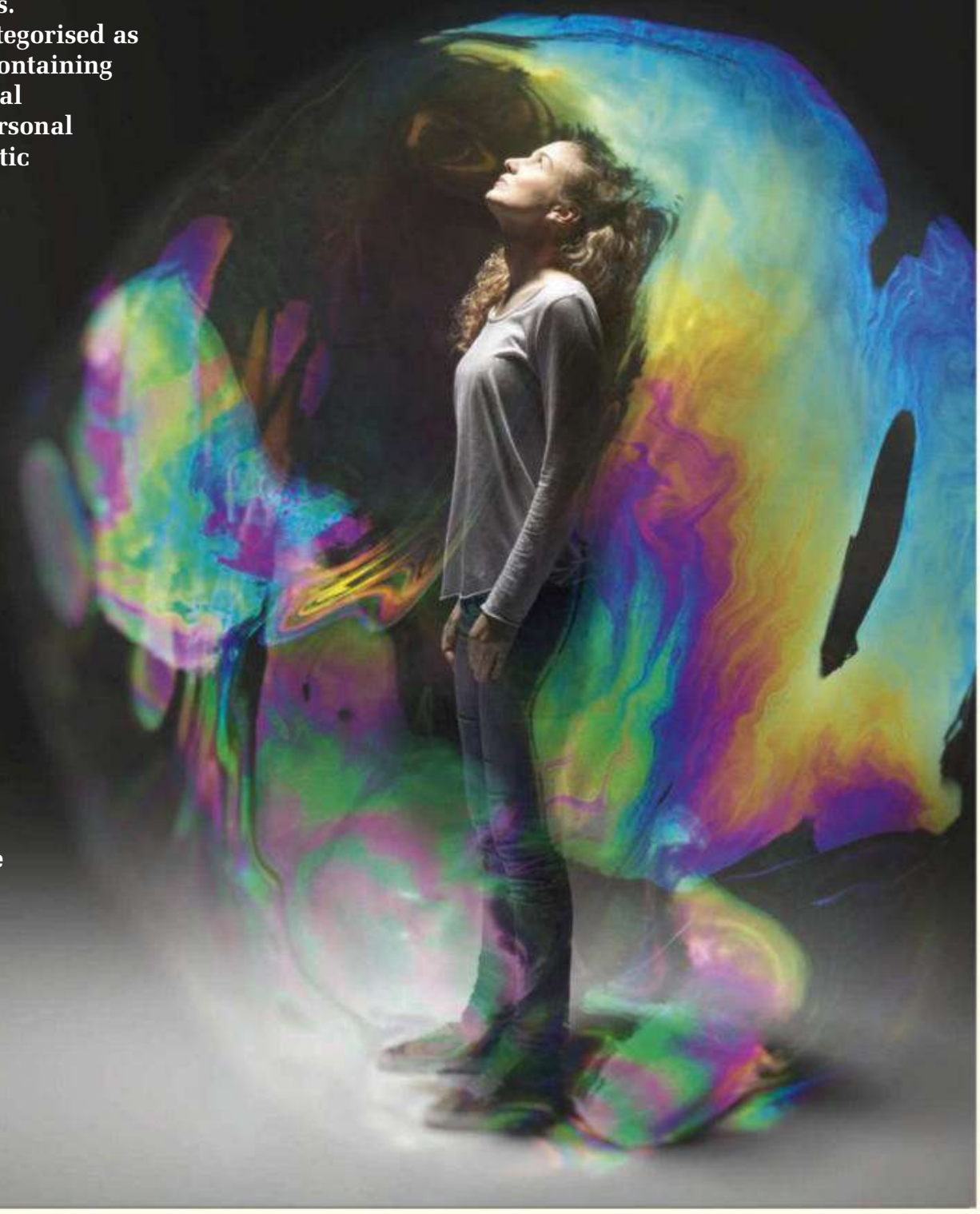
Of these themes, they found that 20 could be categorised as bad dreams, with 55 per cent of the bad dreams containing pandemic-specific content such as failures in social distancing, coronavirus contagion, issues with personal protective equipment, and dystopic and apocalyptic pandemic-related scenarios.

For example, word pairs in a dream cluster labelled 'disregard of distancing' included mistake-hug, hug-handshake, handshake-restriction, handshake-distancing, distancing-disregard, distancing-crowd, crowd-restriction and crowd-party.

"We were thrilled to observe repeating dream content associations across individuals that reflected the apocalyptic ambience of COVID-19 lockdown," said lead author Dr Anu-Katriina Pesonen, head of the Sleep & Mind Research Group at the University of Helsinki. "The results allowed us to speculate that dreaming in extreme circumstances reveal shared visual imagery and memory traces, and in this way, dreams can indicate some form of shared mindscape across individuals."

The study also found that more than half of the respondents reported sleeping more than before the period of self-isolation, with 10 per cent having a harder time falling asleep and more than a quarter having more frequent nightmares. The research could provide valuable insights for medical experts who are already assessing the toll the coronavirus is having on mental health, as sleep is a central factor in most mental health issues.

"Repeated, intense nightmares may refer to post-traumatic stress. The content of dreams is not entirely random, but can be an important key to understanding what is the essence in the experience of stress, trauma and anxiety," Pesonen said. "The computational linguistics-based, AI-assisted analytics that we used is really a novel approach in dream research. We hope to see more AI-assisted dream research in future. We hope that our study opened the development towards that direction."



DR HUGO ZEBERG
Evolutionary geneticist

Horizons

Neanderthal genes could increase the severity of COVID-19 symptoms

DNA inherited from Neanderthals 50,000 years ago seems to be linked to an increased risk of falling ill from the coronavirus

The DNA of people with non-African roots is roughly 2 per cent Neanderthal

ALAMY

HOW MUCH OF THE HUMAN GENOME HAS BEEN INHERITED FROM NEANDERTHALS?

If you have roots from outside of Africa, then roughly 2 per cent of your DNA is Neanderthal. But if we put all these pieces together, we find more than half of the Neanderthal genome in modern humans. But it will differ between people: some carry some pieces, some carry other pieces.

HOW DO WE KNOW THAT MODERN HUMANS INHERITED NEANDERTHAL DNA?

During the last two decades people have been studying this, and a draft Neanderthal genome was published 10 years ago. Svante Pääbo and his colleagues at the Max Planck Institute in Leipzig, with whom I collaborate, managed to extract the whole DNA code from Neanderthal bones that we can compare to people living today. We have three really good Neanderthal genomes: one from a Neanderthal found in Croatia, and two found in Siberia.

HOW DID MODERN HUMANS COME TO INHERIT THIS NEANDERTHAL DNA?

When modern humans entered Eurasia, they met and interbred with Neanderthals and created offspring together. That occurred some 50,000 to 60,000 years ago. More and more data suggests that this interbreeding was prevalent. During the course of the evolution of the species, people have interbred everywhere, whenever they met new people.

WHY HAVE THESE NEANDERTHAL GENES PERSISTED IN MODERN HUMANS FOR SO LONG?

Part of the Neanderthal genome is missing, but we believe that some variants were really detrimental early on. But some are probably there because they were beneficial in a way. We did a study earlier this year and found that a gene variant from Neanderthals actually decreased the risk of miscarriage and bleeding during early pregnancy. So we probably got some good variants and some negative variants.

TELL US ABOUT YOUR STUDY.

There's been a large collaborative international effort led from Helsinki, Finland, where scientists and

"It was really a surprise. When comparing the biggest risk factor, I saw immediately that it was a Neanderthal sequence"

clinicians have genotyped individuals with severe COVID – those people who have ended up in hospital or in the ICU or have even died from the disease. I've played a small part in this consortium, but I also work with the Neanderthal genome so I thought, 'Why not have a look?' When I did, I fell off my chair. It was really a surprise. When comparing the biggest risk factor [of severe COVID], I saw immediately that it was a Neanderthal sequence. It was really striking.

HOW MUCH DOES THE NEANDERTHAL GENE VARIANT AFFECT THE RISK?

Initially we saw it was about a 60 per cent increase in risk per copy of the variant. You get one copy from your mother and one from your father. The latest estimate has actually increased a little bit higher to almost twice the risk if you carry one genetic variant. For a genetic effect, this is quite large. Most genetic variants only slightly influence things.

WHAT SPECIFIC FUNCTIONS DO THESE NEANDERTHAL GENES THAT YOU'VE IDENTIFIED PLAY IN THE HUMAN BODY?

This region contains several immune receptors that are involved in the immune response. So that's very intriguing and interesting. There is also a gene that forms a complex with the receptor for the virus, which is also of high interest, of course.

DO WE HAVE ANY IDEA WHY PEOPLE WITH THESE NEANDERTHAL GENES ARE AFFECTED BADLY BY COVID-19?

It might be the immune receptors. And we know that people who get very sick with COVID-19 seem to have this 'cytokine storm' – some overreaction of the immune system. So this might be part of that, with the body responding too aggressively against the virus.

HAVE WE BEEN ABLE TO IDENTIFY THE PREVALENCE OF SPECIFIC COVID SYMPTOMS IN THE CARRIERS OF THESE GENES?

We see that carrying these genetic variants is much more common in people who end up in hospital and at the ICU, so in those who have a bad progression of COVID-19. One study also saw an increase in need of mechanical ventilation [in these patients]. We don't believe it has so much to do with susceptibility or the likelihood of actually contracting the virus, but rather how our bodies respond to it.

IS IT POSSIBLE THAT THIS COULD HELP US FIND A TREATMENT, OR HELP US IDENTIFY THOSE PEOPLE WHO ARE MORE RISK?

The fact that these genetic variants are from Neanderthals is perhaps more of an academic interest. But, of course, identifying the genes is important for understanding the disease. We, and many others, are trying to understand these genetic variants to see which of the genes in this region is important. So that could point towards future treatment for COVID-19, and it could also help to identify people at risk and might also be very important in dealing with this disease.

DR HUGO ZEBERG

Hugo is an assistant professor in the department of neuroscience at the Karolinska Institute in Stockholm, Sweden. ***Interviewed by*** **BBC Science Focus** ***commissioning editor Jason Goodyer.***

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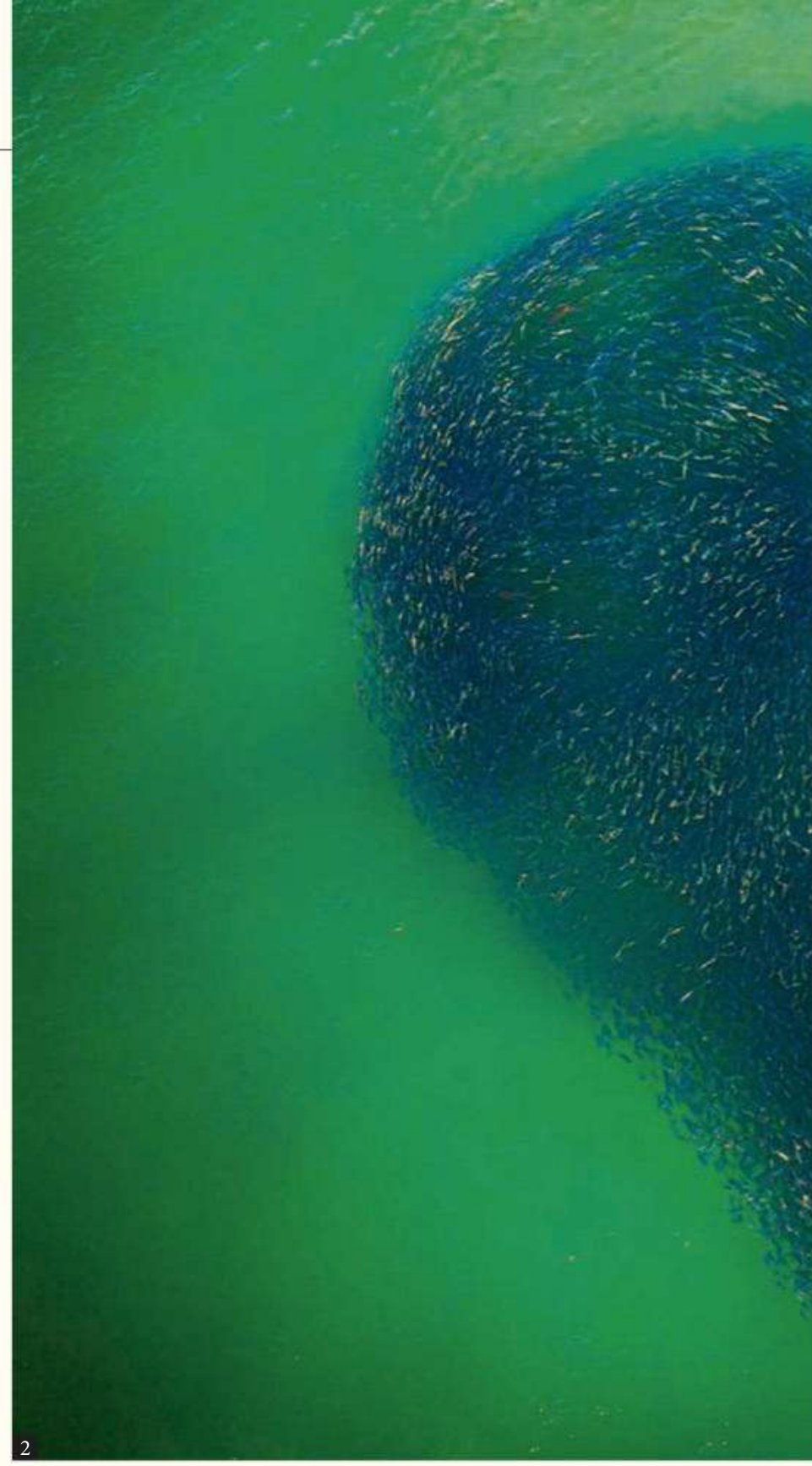
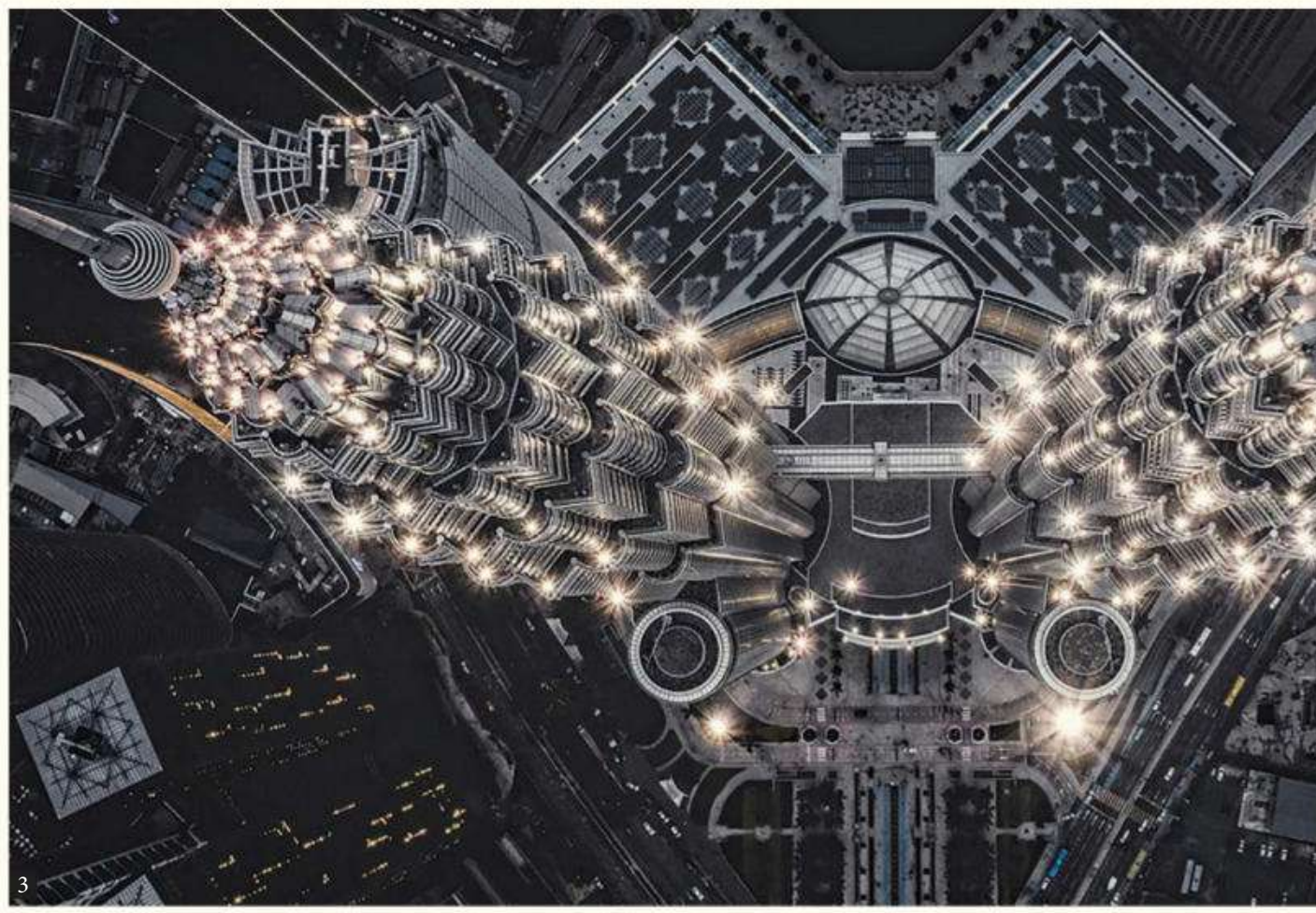


2

PHOTOGRAPHY

2020 Drone Photo Awards announced

The competition is part of the 6th Siena Awards Festival, which is being held at Siena's Accademia dei Fisiocritici – one of Italy's oldest science museums – from 24 October to 29 November



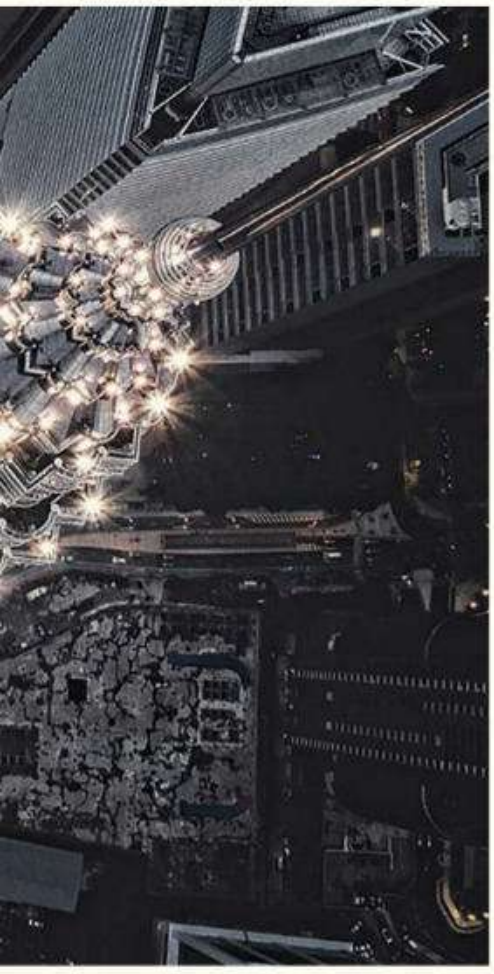
3

1. Swirl
by Boyan Ortse
Australia's stunning pink lakes, like this one, get their dramatic hues from carotenoid pigments secreted by *Halobacteria* and *Dunaliella salina* algae.

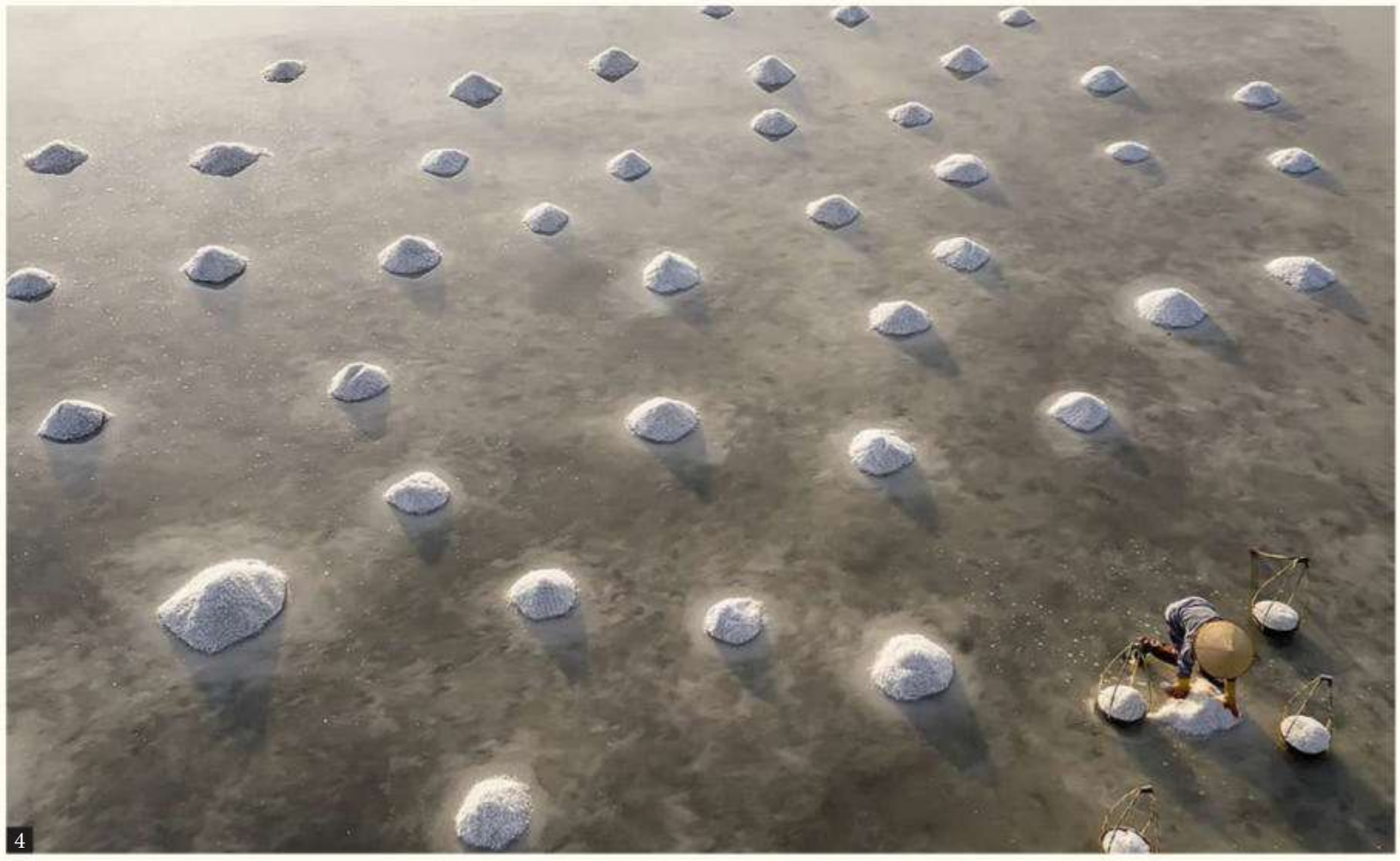
2. Love heart of nature
by Jim Picôt
This picture of a shark swimming through a heaving school of salmon in New South Wales bagged the competition's grand prize.

3. Alien structure on Earth
by Tomasz Kowalsko
Viewed from above, the famous Petronas Towers in Kuala Lumpur look like something from another world. This photo took first place in the Urban category.

4. Mountains of salt
by Igor Altuna
A worker gathers sea salt from a traditional saltern located in a coastal region of Vietnam.



DRONE PHOTO AWARDS 2020



4

PALAEONTOLOGY

Two fingers good, three fingers bad

Sometimes, less really is more: the evolutionary loss of a finger may have helped a group of parrot-like dinosaurs to thrive more than 68 million years ago.

Multiple complete skeletons of a new species of oviraptor – feathered, omnivorous creatures sporting large, toothless beaks similar to the type seen in species of parrot today – were unearthed in the Gobi Desert in Mongolia and subsequently studied by researchers from the University of Edinburgh.

Dubbed *Oksoko avarsan*, the newly discovered dinosaurs were found to have just two fingers on each forelimb – one less than other members of the oviraptor family. This is the first time that digit loss has been observed in the three-fingered family of oviraptors and may suggest adaptability that enabled the animals to spread during the Late Cretaceous Period in which they thrived.

The team discovered that the species was a social animal when young, as the fossil remains of four juvenile dinosaurs were preserved resting together.

"*Oksoko avarsan* is interesting because the skeletons are very complete and the way they were preserved resting together shows that juveniles roamed together in groups," said study leader Dr Gregory Funston, of the University of Edinburgh's School of Geosciences.

"But more importantly, its two-fingered hand prompted us to look at the way the hand and forelimb changed throughout the evolution of oviraptors, which hadn't been studied before. This revealed some unexpected trends that are a key piece in the puzzle of why oviraptors were so diverse before the extinction that killed the dinosaurs," he added.

The team also tracked the reduction in size, and eventual loss, of a third finger across the oviraptors' evolutionary history. They found that the animals' arms and hands changed drastically in tandem with migrations to new geographic areas – specifically to what is now North America and the Gobi Desert.

The fact that oviraptors were able to evolve forelimb adaptations suggests that they could alter their diets and lifestyles more quickly and efficiently than other dinosaurs, enabling them to diversify and multiply, the researchers say.

ABOVE *Oksoko avarsan* had two digits on each forelimb, and a parrot-like beak

BELOW The dinosaur fossils were found together, suggesting that they were sociable animals as juveniles

GREGORY FUNSTON, MICHAEL W SKREPNICK, GETTY IMAGES

Pre-pandemic study shows more than half of us want more physical contact

A global study has revealed our attitudes towards interpersonal touch, reminding us of its importance during times of social distancing

Nearly 40,000 people from around the world have taken part in a study to reveal global responses to touch. Results show that attitudes are nuanced, though age and personality had a strong influence on a person's inclination, or aversion, to physical contact.

In the midst of the coronavirus pandemic, being touched by a stranger is a frightening thought. Those who are self-isolating have limited or even no physical interactions, while doctors and nurses on the frontline feel the pulses of their patients only through layers of PPE.

But for a surprising amount of people, being deprived of touch is not a new feeling. Over half of respondents to The Touch Test, which ran from 21 January to 30 March 2020, said they got 'too little touch' in their day-to-day life. Of all participants, only 3 per cent said they had too much interpersonal touch.

However, nearly one-third of people did not feel positively about touch. Further analysis by academics at Goldsmiths, University of London, revealed that those who said they didn't like touch were also likely to say they found it difficult to form trusting relationships.

"These results show that our likes and dislikes around touch are nuanced and vary from person to person," explained Claudia Hammond, who presented the results of The Touch Test on BBC Radio 4 in October. "Half of the people who took part in the study feel, even before the pandemic, [that] today's society does not provide enough opportunities for interpersonal touch. But it's clear that not everybody wants more touch. Personal preference is foremost when it comes to touch."

While we are now carrying out social distancing and are actively encouraged not to touch anyone outside our household, The Touch Test showed that 63 per cent of people disliked being touched by a stranger, pre-pandemic. Younger people were found to dislike this much more than older people.

When it came to romantic relationships, 88 per cent said they liked engaging in public displays of affection. At home, just under two-thirds of people said getting a hug from their partner before bedtime had a positive effect on their sleep.

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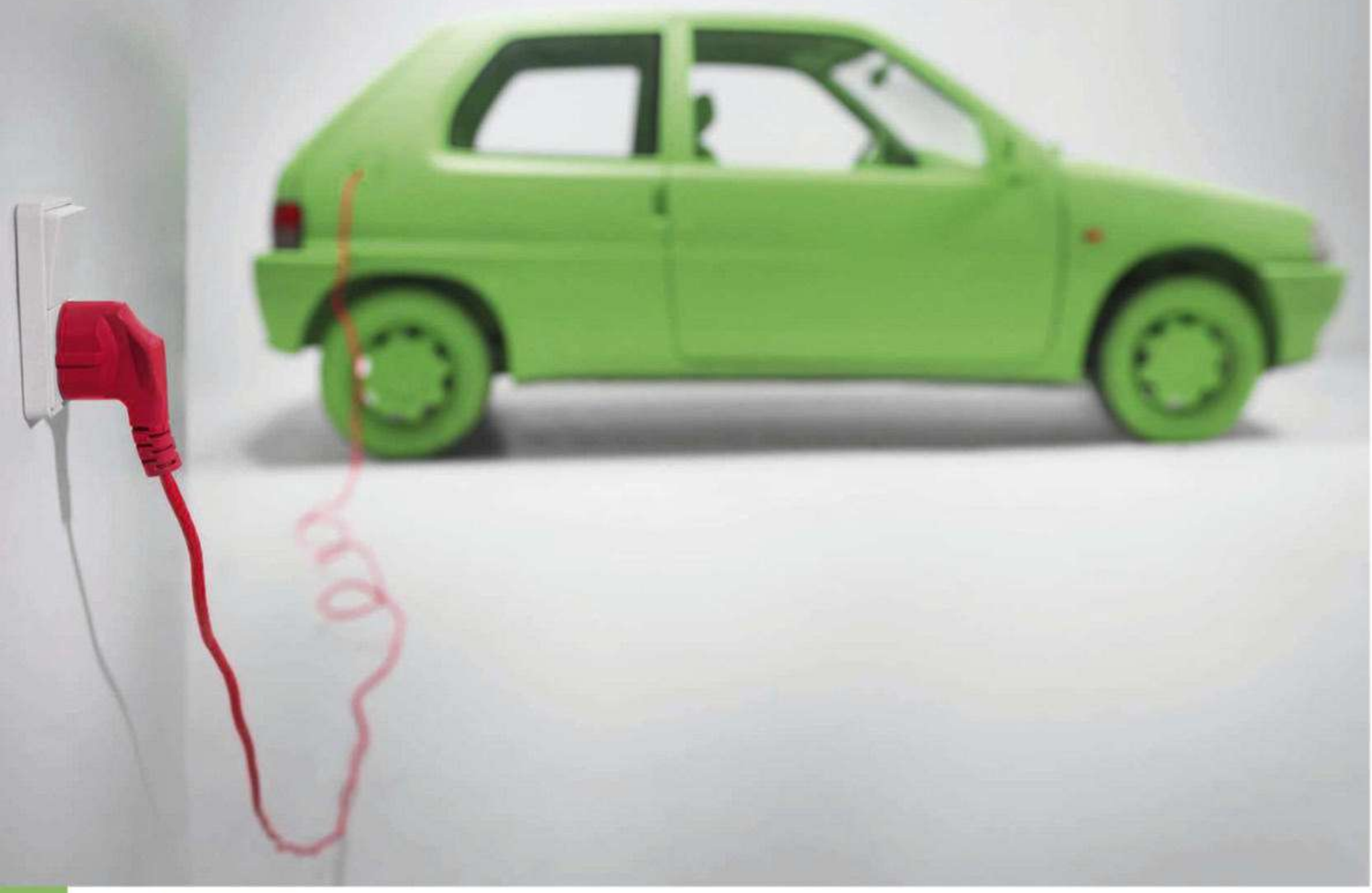
SCIENCE BEHIND THE HEADLINES

Plug-in hybrids | Long COVID | Is COVID-19 mutating?



REVIEW

PLUG-IN HYBRID CARS: ARE THEY REALLY THE ECO-FRIENDLY CHOICE?

A study has found that plug-in hybrids actually emit more than 2.5 times as much CO_2 as tests claimed. So, are they worth having?

"Nobody ever checked whether you're actually using it as intended, you're merely getting a car with several thousand pounds off the cost"

BBC

Visit the BBC's Reality Check *website at* ***bit.ly/reality_check_*** *or follow them on Twitter* ***@BBCRealityCheck***

Plug-in hybrid electric vehicles (PHEVs) are supposed to be the perfect compromise between practicality and carbon emissions, with an electric motor to handle your commute and an engine for range. But they might not be as eco-friendly as they appear. A new report from the campaign group Transport and Environment (T&E) has shown that PHEVs emit, on average, over 2.5 times more CO_2 than their official test values. The group recommends that the UK government commits to the 'earliest feasible phase-out date' for all cars with engines: internal combustion engine (ICE) cars, conventional hybrids and PHEVs.

HOW MUCH CO_2 DO PHEVs EMIT?

Laboratory tests for PHEVs found that they emit, on average, around 44g of CO_2 per kilometre. However, T&E analysed fuel efficiency data from 20,000 PHEV vehicles around the world and found that the 'real world' value is 117g of CO_2 per kilometre.

For comparison, a conventional hybrid – or 'self-charging' hybrid, which draws electric power from the brakes – emits only slightly more, at 135g of CO_2 per kilometre. A new ICE car emits between 164 and 167g of CO_2 per kilometre.

WHY DO PHEVs EMIT SO MUCH MORE THAN EXPECTED?

Plug-in hybrids have the potential to run on their electric battery only, often allowing a range of at least 32 kilometres (20 miles) with zero emissions. However, the driver does need to plug it in regularly to keep it charged – something which T&E claims that most real-world users don't do.

Dr Ian Walker, who studies environmental psychology at the University of Bath, isn't surprised by this behaviour. "I think we have to ask, is anybody actually buying these because of their environmental concern?" he says. His research has found that environmental considerations are low down the list of factors people consider while buying a car – he calls it a 'tertiary consideration'. "The people who genuinely are concerned about the environment are not driving a car at all, or they're certainly not using them the way most cars are being used," he adds. He points out that many PHEVs are SUVs, which use "dramatically more" energy than smaller cars.

So, why do people buy PHEVs at all, if not to use its electric motor? A big reason, Walker suggests, is the government's grant scheme, which reduces the cost by up to £3,000. "Nobody ever checked whether you were actually using it as intended," he says. "You're merely getting a car with several thousand pounds off the cost."

But even if you do use your PHEV as intended, that doesn't guarantee that it will drive on battery mode. "Even when a PHEV is driven in the supposed zero-emission mode, most continue to use their engine, burning fuel and emitting CO_2," the T&E report claims. The report found that many models reverted to engine mode when outside temperatures were too cool or the speed was too high. "The reality is it is almost impossible for the car to drive in zero-emission mode, even for short distances, on a regular basis," it says.

BELOW According to campaign group Transport & Environment, many people with plug-in hybrid cars don't actually bother plugging them in

ALAMY, GETTY IMAGES

“We’re carrying on with 1960s lifestyles and just fretting about what the motors are going to look like”

SHOULD WE STILL BUY PHEVs?

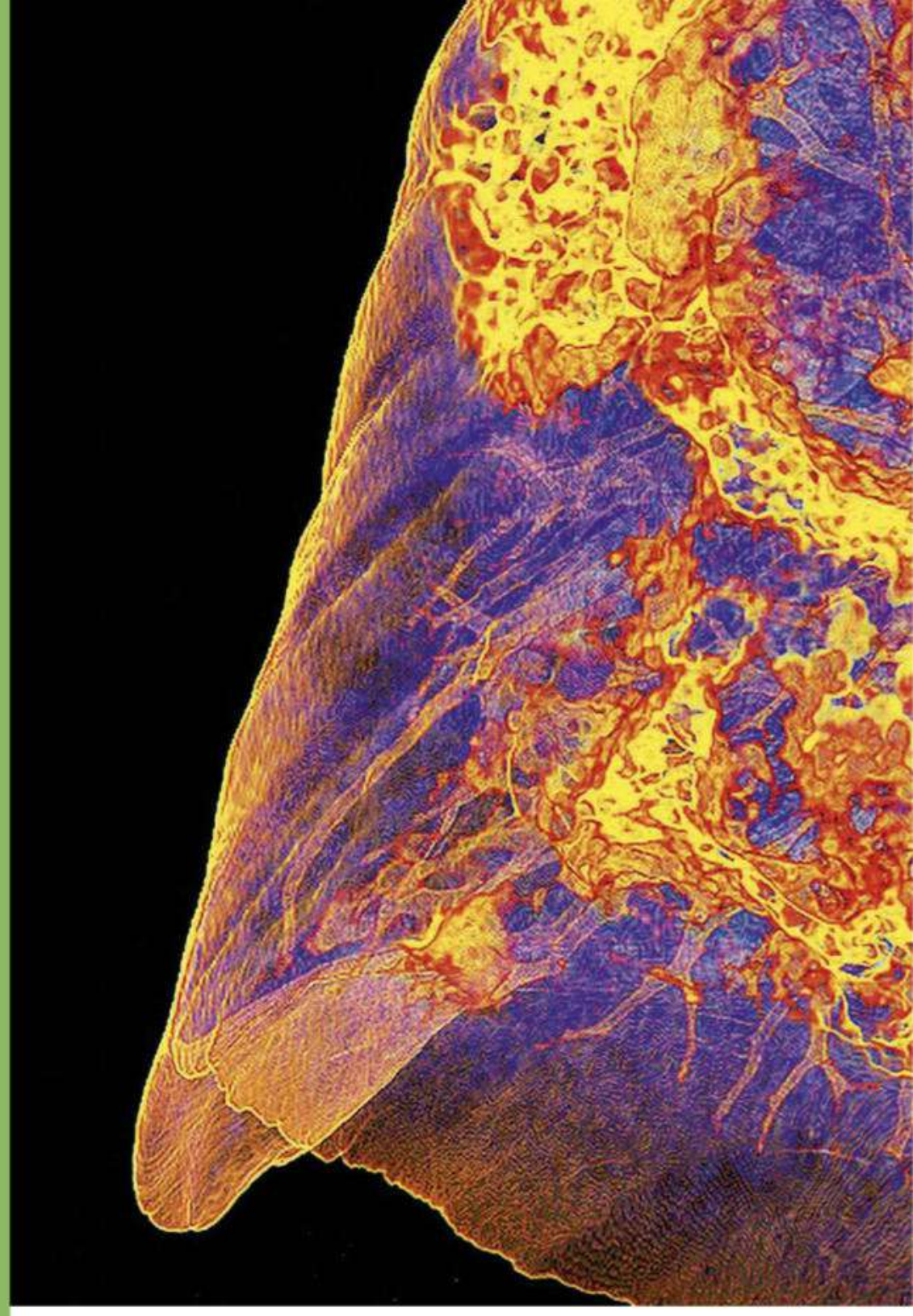
Walker believes that the debate over the best type of car is asking the wrong question. “It feels like the discussion starts with the assumption that everybody is going to have a car and use it all the time,” he says.

Instead of finding the best car for our lifestyles, we should be changing our lifestyles so we don’t need to drive everywhere.

“Where should people live and work? How should they get between those places? Should urban planning not trap you into a car-dependent lifestyle?” he asks. “We’re carrying on with 1960s lifestyles and just fretting about what the motors are going to look like. And it’s the wrong question. We need to be looking at our lifestyles, our goals, what we want to accomplish and how we want to live and who we want to be, and then working out how to get there rather than just saying, is it petrol, diesel, or battery?”

by **SARA RIGBY**

Sara is the online assistant at BBC Science Focus.

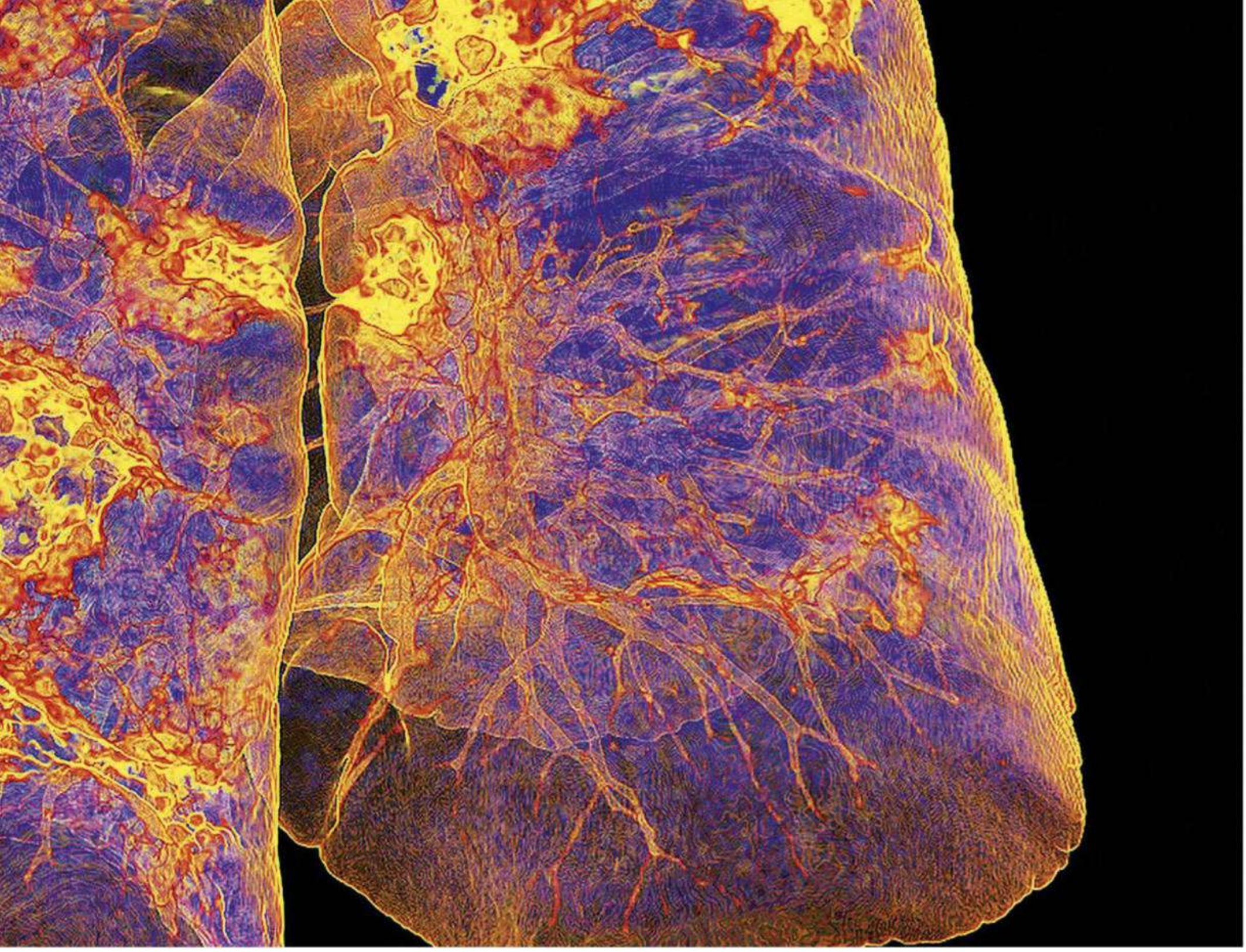


ANALYSIS

LONG COVID: JUST HOW COMMON IS IT?

Some COVID-19 patients are reporting symptoms long past their two-week quarantine. What do we know about people experiencing chronic fatigue and breathlessness months after their COVID-19 diagnosis?

As many as 1 in every 10 COVID-19 patients could end up with symptoms lasting for longer than three months, with sufferers around the world terming this ‘long COVID’. Researchers believe that these symptoms are the ‘after-effects’ of the virus, due to damage caused to the organs, immune and nervous systems. People who have been ill enough with COVID-19 to be hospitalised are more likely to need an extended recovery time than those who weren’t as badly affected, but it seems long COVID can strike anyone, of all ages and backgrounds.



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ABOVE CT scan of lungs affected by COVID-19 atypical pneumonia (patchy red and yellow areas)

We already know that there are viruses that can cause symptoms for weeks, months or years post-infection. Some long-term illnesses, such as myalgic encephalomyelitis (ME) and chronic fatigue syndrome, are thought to be post-viral, so it would make sense that COVID could also cause long-term problems. Dr Matthew Knight, a specialist in respiratory medicine, has seen patients with ME in his clinic. These patients, he says, clearly show a process of deterioration over the course of many months and years. Now, he is seeing people visit the hospital with extreme fatigue, months after getting COVID-19. Will they have that picture of long-term ill health, too?

Patients with COVID symptoms seem to fall into three cohorts, Knight says. He researched the condition with professor of primary health care Trisha Greenhalgh, and respiratory physiotherapist Maria Buxton.

Patients with acute COVID are those who are between day 1 and day 21 of symptoms. Most patients fall into this category, but there will be some – perhaps up to 20 per cent of all COVID-19 patients, according to the few studies currently published – who have symptoms for at least 12 weeks. Those who have symptoms between weeks 3 and 12 are being called 'post-acute COVID patients'. "This describes the constellation of symptoms between these weeks, which in the vast majority will resolve themselves," says Knight. "Breathlessness, fatigue, cough, headache, diarrhoea, skin rashes and low mood are all symptoms in that phase that we would expect to gradually improve." It's unclear whether these people are still infectious.

Chronic COVID, or long COVID as it's now widely known, is when those symptoms are present beyond 12 weeks. "Early evidence and early clinical experience seems to suggest that those symptoms won't just disappear, or certainly not rapidly," explains Knight.

It's hard to know how common long COVID is. Knight says that the best figures have come from the COVID-19 symptom tracker app, which suggest that somewhere between 1 and 10 per cent of people still have symptoms at 10 to 12 weeks. At the time of writing, 530,000 people in the UK have contracted COVID-19. That means anywhere between 5,000 to 50,000 patients could be suffering with long COVID.

"We, and a number of others, have come to the conclusion that 60,000 is a good, educated guess," says Knight. "That figure is at least the minimum that we should be planning for, [and] that we should be

preparing to offer services for and rehabilitation. We shouldn't overestimate the size of the problem. It's not that everyone with COVID is going to have this. But it's more than just a rarity. It's enough people to justify serious study and review."

So, what do scientists know about who is and who isn't likely to suffer with symptoms more than 12 weeks after diagnosis with COVID-19? Very little, it seems, as the focus until recently has – rightly so – been on treatments and vaccines. However, research does seem to suggest that having a coexisting illness makes you more likely to get long COVID. But it can and does occur in otherwise healthy people, of all ages.

Of those who have long COVID, there seem to be two types. "There are those that have got demonstrable, organic pathology. Scarring on their lungs, damaged cardiac muscle or neurological damage. Those patients seem to be the minority, certainly in my clinical practice based in Watford," says Knight.

Then there are the long COVID patients who report fatigue as the predominant symptom, but also breathlessness, joint pain, diarrhoea and more. "These patients have got more normal X-rays, normal CT scans, normal lung function tests," says Knight. "For them, no one really knows what the cause of [their symptoms] is."

There is expertise and treatment in place for damaged hearts and lungs, but for fatigue-predominant patients, there is no such framework.

"I've spoken to colleagues and doctors who've had COVID […] They're three, four or five months down the line, and speak about a profound exhaustion. These are real symptoms people are describing, and they need to be taken seriously," says Knight.

by AMY BARRETT
Amy is the editorial assistant at BBC Science Focus.

COMMENT

COVID-19: IS IT MUTATING?

A number of media outlets reported that the coronavirus is mutating. Is it a cause for concern?

Viruses replicate during the infection process. For most viruses, replication results in many errors, which means that viruses like the flu mutate rapidly. This can lead to treatments and vaccines becoming ineffective, and is one of the reasons why we need a new flu jab every year.

Coronaviruses will accumulate mutations, but they do so at a slower rate because they 'proofread' their replicated genome. Mutations do occur, though, and could have many different effects on the SARS-CoV-2 coronavirus and our ability to control the pandemic.

The majority of mutations will have no impact on the virus or on the disease. Occasionally a mutation will enable greater growth or transmissibility, or will escape from the immune system (meaning the immune system no longer responds to it), in which case the mutated virus may spread widely throughout the population. However, it is important to note that increased virus replication or transmission does not necessarily mean that the virus will become more deadly. For SARS-CoV-2, its ability to spread asymptomatically and pre-symptomatically is what has made the pandemic much more difficult to control and has greatly increased the number of infections. The 2002-2003 SARS-CoV-1 virus was a more lethal virus, but the outbreak was easier to control because it spread after symptoms began.

Causing serious disease is not always in a virus's 'best interest'. We have already seen this phenomenon occur with the much-discussed D614G mutation of SARS-CoV-2, which arose in February 2020. This was a mutation in the virus's spike protein. The mutation enabled the virus to transmit more effectively from person to person, but did not affect the disease severity. Due to this enhanced transmission, the D614G variant became the dominant form of the virus by March 2020 and continues to be the main form seen in most infections.

The D614G mutation is not the only mutation that has been observed in SARS-CoV-2. So far, however, no other mutations have been observed that change the

SCIENCE PHOTO LIBRARY

"The D614G mutation enabled the virus to transmit more effectively from person to person, but did not affect the disease severity"

virus's replication, transmission, disease or immune evasion. These mutations are still possible at any time, and the longer the pandemic continues the more likely it will be that we will see another important mutation arise. Any mutation may change the behaviour of the virus, though when and in what way is impossible to predict.

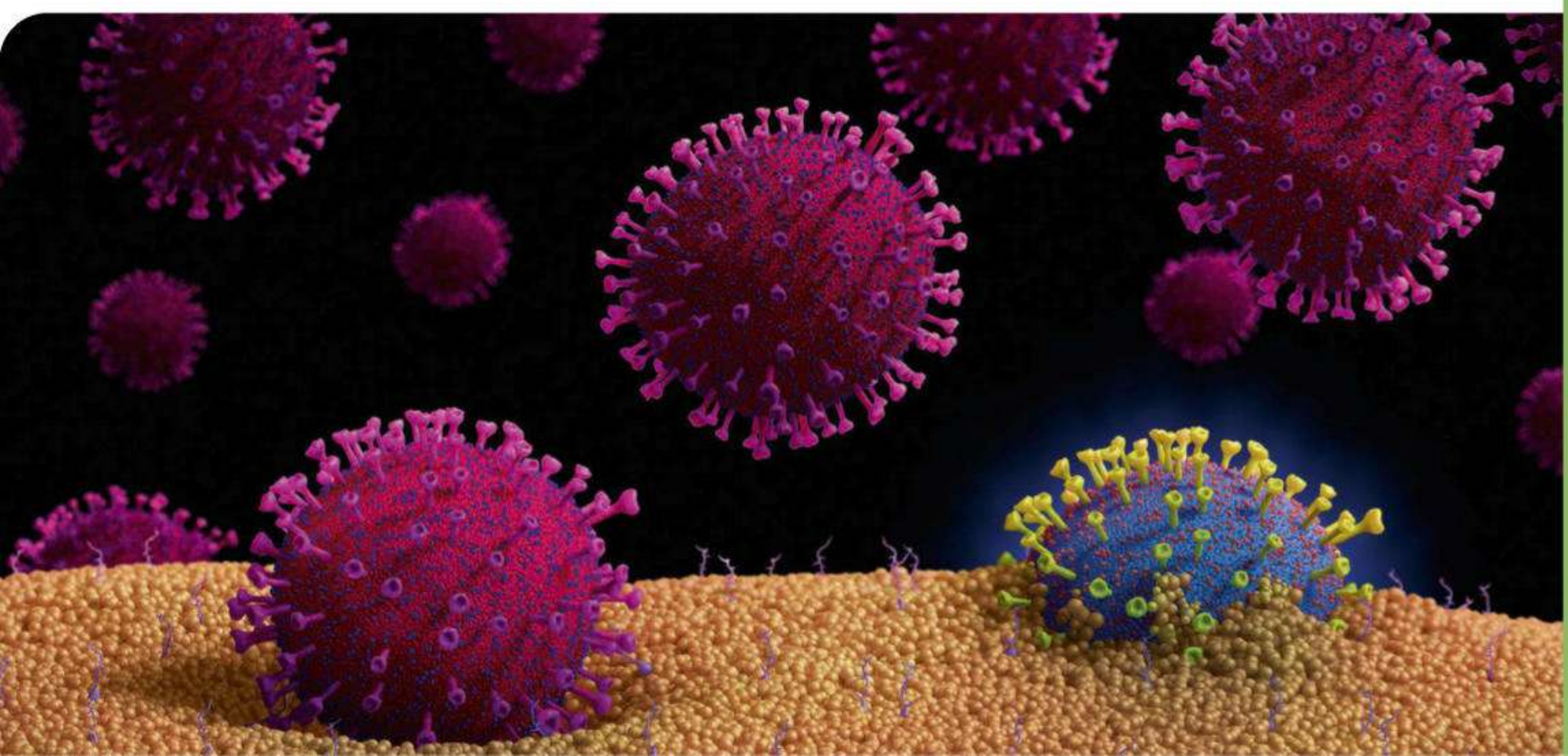
The impact of viral mutations could change once we start using antiviral therapeutics and vaccines. The use of these treatments puts a selective pressure on the virus, effectively rewarding mutations that render the treatment ineffective. For example, the antiviral drug remdesivir targets the polymerase protein that replicates the viral genome. Normally, mutations in the virus polymerase protein are disadvantageous as they can impair the function of a critical virus protein, but if the mutation stops remdesivir from working, then the virus can continue to replicate and spread, and remdesivir would not longer work against the virus.

Similarly, some vaccines, such as the Oxford ChAdOx1 vaccine, generate immune responses to the viral spike protein. Mutations could alter the spike protein so that vaccine-generated antibodies would not recognise it so well, reducing vaccine effectiveness. But there are 316 therapeutics and 213 coronavirus vaccines currently in development. If we see mutations arising that alter the effectiveness of any one therapeutic or vaccine, we may then be able to vary or combine therapeutics, preventing the virus from escaping the treatment.

As SARS-CoV-2 mutates slowly, it is likely that our new treatments will continue to be effective and the behaviour of the virus will not dramatically change over the coming months. It is important to work toward viral containment and ending the pandemic, because the longer the virus continues to circulate, the greater the chances of a new mutation emerging. **SF**

by **DR JEREMY ROSSMAN**

Jeremy is a senior lecturer in virology at the University of Kent.



BELOW The proteins present on the 'spikes' of the SARS-CoV-2 virus allow it to invade human cells

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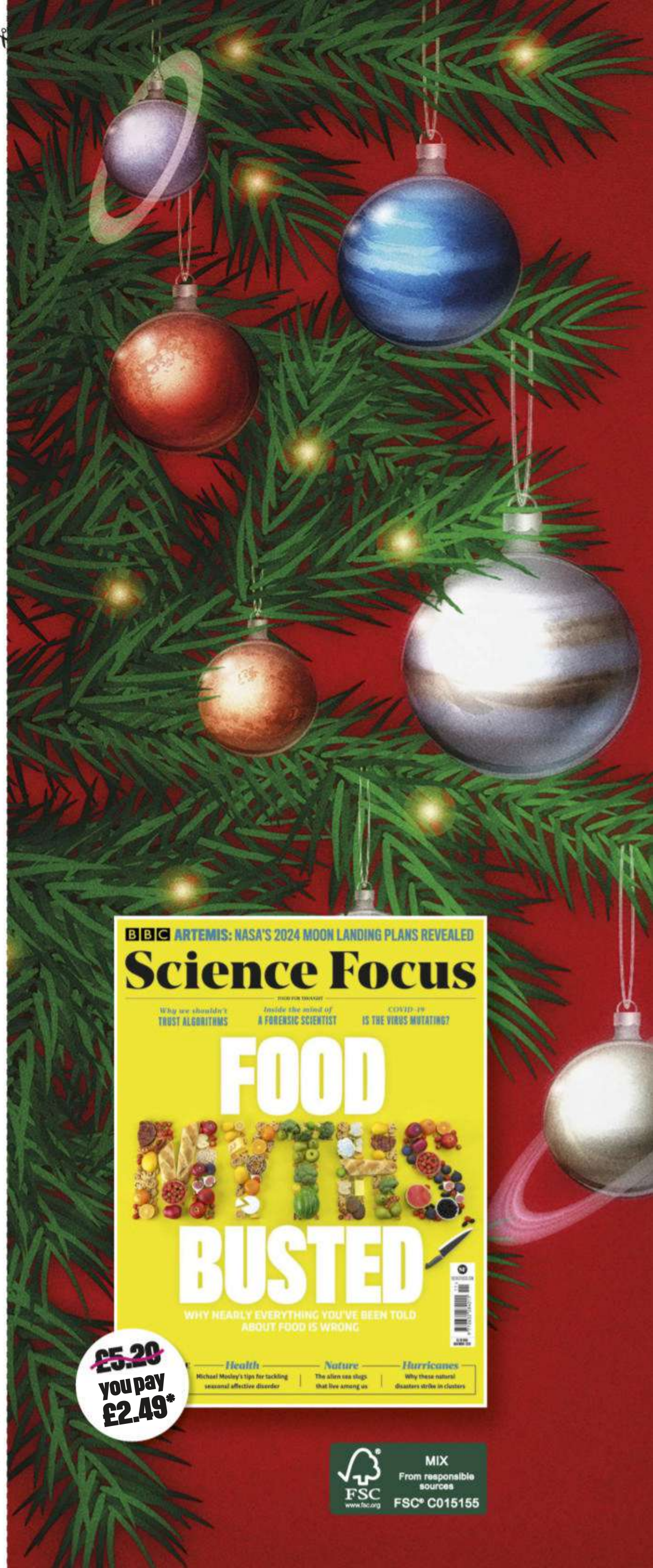
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Our pick of the best smart speakers out now p44

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

Amazon's Ring Always Home Cam rises out of its docking station to keep on eye on your house

NEW FROM AMAZON

Luna

Soon you'll be able to stream video games via your Fire TV stick, which you can play with a special Luna controller. You'll need a lightning-fast internet connection to get the best out of it though.

Ring Car System

This security system will monitor for impacts, break-ins and tows, and starts recording when it senses something untoward is happening. And presumably Alexa will ask them nicely to stop (okay, we made that last bit up).

Echo Show 10

This smart display is ideal for following cooking recipe videos or keeping the kids quiet in another room. The base is motorised so it can follow your face around the room, making video calls a breeze.

SMART HOME

Alexa, can you read my mind?

Amazon reveals its vision for a smart home that knows what you need without having to ask... now with indoor drones

Don't you want to talk less and smile more? That seems to be Amazon's vision for the future of the smart home. According to the company that literally invented the smart home voice assistant, talking to their devices is just a temporary stage. Next, their gadgets will 'just know' what we want and do it for us without a single command. To plot this route, the consumer tech giant showed off a slew of new gadgets at its annual hardware event in September.

This vision of an 'ambient home', as outlined by Amazon's senior vice president David Limp at the event, has been the roadmap for home automation for decades. A true smart home doesn't just react to commands, it's predictive and proactive, working out what you need, when you need it. This could include lights switching on when you arrive home, heating turning off when the house is empty, or security drones activating when an intruder breaks in. Amazon says it's ready for this domestic revolution, even if it's still a few decades off.

"THEIR GADGETS WILL 'JUST KNOW' WHAT WE WANT AND DO IT FOR US WITHOUT A COMMAND"

The first step is connectivity. The revamped Echo smart speaker line that was recently unveiled doesn't just have a showy new spherical look and some pretty fabric covers, it comes with a suite of tech to keep everything connected. The fourth-generation Echo, along with the new Echo Show 10 smart display, both include a Zigbee smart home hub, along with Wi-Fi and Bluetooth Low Energy. And all the Echos act as bridges for Amazon Sidewalk – a low-bandwidth network that stretches the connectivity of your home beyond the four walls to the pavement and even to your neighbours' garden, if they are so obliged. This extended network, which will launch in the US later this year, is designed to support expanding the smart home out to the smart garden and the smart driveway and beyond to the smart neighbourhood.

Back inside the home, Alexa is also getting smarter. The AI will be able react to common household sounds, such as a baby crying or a dog barking, and do helpful things like turn on the light in the nursery or play music to soothe the dog. The latest features are powered by Amazon's new chip, the AZ1 Neural Edge processor, which will be built into new Echo devices and the Echo Show 10. It promises to supercharge the AI's ability to learn, and will make it faster and more natural.

At the event, Amazon also showed off an actual robot. The Ring Always Home Cam ($250, coming in 2021) was perhaps the most dystopian offering from the event, and certainly raised a fair number of eyebrows. At roughly 13cm high, the Always Home Cam is a drone with what looks like a video doorbell attached to it. It rises up from its docking station and flies on pre-set paths at your request. If a security event is detected, it streams footage to your phone.

Ultimately, the ambient smart home won't rely on voice commands or creepy drones. Instead, less obtrusive tech such as sensors, computer vision, and AI will work together to respond to our needs without infringing on our privacy. But, as Limp says, the ambient home "is a long-term vision, and there's still lots to be done to make that a reality".

AMAZON

BUYER'S GUIDE

Best smart speakers

Do you need a smart speaker? No. Should you get one? Totally. ***Jennifer Pattison Tuohy*** *picks her favourites*

Smart speakers are to speakers what smartphones are to phones; a technology that turns a utilitarian device into something that can do so much more. After a slow start, smart speakers are becoming increasingly popular, with almost 3 out of 10 Brits now owning one. With a smart speaker, things you to have to dig out your phone for, or hop on a computer to accomplish, can be done hands-free just by speaking a few words. Look up the opening hours for a museum while you're packing lunch, set a timer for your boiled egg, add more eggs to your shopping list, all with just a few words. Some smart speakers also have screens attached, to give you visual feedback (such as showing you which song is playing) as well as providing the family with another place to watch Netflix. We tested 15 smart speakers, featuring the three most popular voice assistants – Google Assistant, Amazon Alexa and Apple Siri. We put each model through the same tests to evaluate its audio quality and listening responsiveness. This included sending commands from different distances, at different volumes, with background noises, as well as asking the same questions and giving the same commands to determine which performed the fastest and most appropriately.

What you need to know...

BLUETOOTH SPEAKER OR SMART SPEAKER?

A Bluetooth speaker mirrors the sound coming from your computer or phone – that's every sound, including when someone calls your phone or the ding when you get a new email. This can ruin the mood if you're chilling with some tunes. A smart speaker connects to the internet using Wi-Fi and streams music directly – from a service such as Spotify or Apple Music – no interruptions necessary.

Most of the time, a smart speaker can also work as a Bluetooth speaker, but the best feature of smart speakers is they work with each other, wirelessly. That means multi-room audio without the headache of running wires through your ceiling. Simply pair two, three, four or more compatible speakers together and use your voice to play the same song throughout your house.

PICK YOUR AI

All smart speakers come with virtual assistants on board, Alexa and Google Assistant are the top two, with Siri coming a distant third (the Apple HomePod is the only speaker that works with it). They all use AI to recognise and respond to your voice commands. The best assistant varies, depending on what you'll be using it for. Alexa is great with Amazon Music, Prime Video, Ring smart home devices, Audible audiobooks, and for buying stuff off Amazon. Google plays best with YouTube Music, YouTube videos, Google Play books and movies, and Google Nest smart home devices (like the Nest Thermostat). Siri works seamlessly with all Apple products and services, as well as any Apple HomeKit smart home devices. Most other popular, platform-agnostic streaming services and smart home devices (such as Spotify, TuneIn, BBC Radio, Netflix, Philips Hue smart lights and Arlo security cameras) work with all three.

SMART SPEAKERS CAN MAKE YOUR HOME SMARTER

Speaking of smart home devices, adding a smart speaker to your home makes controlling any home-automation gadgets much easier. Again, there's no

need to get out your phone to turn your lights on, just ask and you shall receive. A smart speaker with a screen also lets you quickly view footage from any smart security cameras you might have and see who's at your door if you have a video doorbell.

Smart speakers also enable what are called Routines by Amazon and Google (and Automations by Apple). These are easy-to-set-up programs where you can daisy chain devices together in your virtual assistant's app and then activate them just by giving your speaker the command. For example, tell your Google smart speaker 'It's bedtime' and have your connected lights turn off, your smart door locks lock, and your thermostat turn down.

Other smart features on offer include using your speakers as an intercom system between different rooms in your house ('OK, Google, broadcast to the living room that dinner is ready'), to control your television with your voice if you have a compatible smart TV ('Alexa, play *Tiger King* from Netflix on my Living Room FireTV'), or to make and receive phone calls (even video calls if you have a smart display – Zoom is coming to Google and Amazon smart displays very soon).

ARE THEY ALWAYS LISTENING?

Yes. When plugged in and turned on a smart speaker is always listening… for its wake word. Be it 'OK, Google' or 'Alexa' or 'Computer' for Amazon Echo speakers, or 'Hey, Siri' for Apple gadgets, the AI in your device is constantly scanning audio for that word, and when it hears it, will start recording. All smart speakers have a mute button and can be unplugged, which might be worth doing during any sensitive conversations.

The security in these devices is excellent, and it's just as difficult for a 'hacker' to tap into the microphone on your smartphone as it is to get into your smart speaker. But if you don't like the idea that Amazon and Google are processing and harvesting data about you through these devices, you can tell your speaker to delete voice recordings and manage what they know about you (Apple does not tie Siri voice recordings to your account.)

The options...

SONOS ONE

PRICE: £179.99
ASSISTANT: ALEXA, GOOGLE ASSISTANT
COLOURS: BLACK, WHITE
SPEAKERS: TWO CLASS-D DIGITAL AMPLIFIERS, ONE TWEETER, ONE MID-WOOFER
SIZE: 161.45 X 119.7 X 119.7MM, 1.85KG

OUR CHOICE

This little speaker packs a lot of punch. It has two voice assistants, and hooks into Sonos's wider world of wireless music, making it the most versatile speaker we tested. It also works with Apple's AirPlay system (letting you play music directly from your iPhone).

The Sonos One works incredibly well as a smart voice assistant, especially considering it's not made by Amazon or Google. This is a big reason why it's our top choice; you're not locked in to one ecosystem as you are with most other smart speakers, you can switch between Alexa and Google at will. If you're just dipping your toe in the smart speaker waters, this is the perfect way to try them out.

The Sonos One responded to our commands, as speedily as any of the Alexa or Google devices we tested, turning on our connected lights in the same amount of time, and streaming our 'dinnertime' playlist from Spotify in seconds. It also has a more appealing design than the native offerings.

Its app is a bit fiddly and had some connectivity issues in our testing – but with voice control added you don't need to mess with it much, just say the word. Also, Sonos won't let you pair its speakers with non-Sonos speakers to take advantage of Amazon or Google's multi-room audio – a symptom of not committing. But you can group all your Sonos device together in Amazon's Alexa app. This lets you add your Sonos speakers to Alexa Routines and do fun stuff like have them start playing music when you arrive home, or put on a soothing playlist at bedtime.

AMAZON ECHO DOT (3RD GENERATION)

PRICE: £49.99
ASSISTANT: ALEXA
COLOURS: BLACK, GREY, PINK, WHITE
SPEAKERS: 1.6" SPEAKER, 3.5MM AUDIO LINE OUT
SIZE: 43 X 99 X 99MM, 300G

BEST ON A BUDGET

If sound quality isn't top priority (or you have a nice home audio setup already), the Echo Dot is the best place to start your smart speaker journey. The cheapest real speaker in the Echo line (which includes the largest variety of smart speakers of any manufacturer), the Echo Dot houses Alexa, Amazon's voice assistant, and produces a decent amount of sound for listening to the radio, a podcast or audio book, or some tunes (in a pinch).

Crucially, it has an audio out option, so you can connect it to superior speakers with a simple audio cable and get the smart speaker benefit for less, a feature that Google's similarly priced Nest Mini doesn't offer. It also works as a Bluetooth speaker.

The biggest benefit of the Dot is it's small, cheap, sounds fine and can do everything any of the bigger Alexas can. If you want to do the whole home audio thing for less and have voice control of your smart home in every room, the Dot will do the job without breaking the bank.

Amazon just announced the fourth-generation Echo Dot, but other than a few small tweaks and a radical new spherical look, it's basically the same device. This is good news, as given Amazon's penchant for sales, you should be able to scoop up a third-gen Dot for a steal right now.

NEST HUB MAX

PRICE: £219.99
ASSISTANT: GOOGLE
COLOURS: WHITE, BLACK
SPEAKERS: TWO 18MM TWEETERS, A 75MM BASS DRIVER
SIZE: 182.55 X 250.1 X 101.23MM, 1.32KG

BEST WITH A SCREEN

The Nest Hub Max is our favourite smart display (smart speaker with a screen) because it can recognise who is using it and serve up personalised information (my calendar appointments for the day, not my husband's) without you even having to say a word, taking the smart speaker to the next level.

It also combines a good stereo speaker that contains all the capabilities of Google's smart assistant with a gorgeous touchscreen that you can use to watch Netflix, flip through YouTube, or follow along with recipes while you're cooking. The video chat feature can even pan and zoom the built-in camera to keep you in the frame while you're on a call – helpful if you're like us and multitask while talking.

When it's not in use, the screen can double as a digital photo frame. It automatically pulls photos from your Google Account and intelligently selects the best ones (so you don't get random screenshots), and uses an ambient light sensor that automatically adjusts the brightness, making digital images look like real printed photos.

On the talking less front, it also works with hand gestures – raise one to stop the music or video playing and raise it again to resume. As much as we enjoy talking to our smart speakers, there are times when it just isn't appropriate, and the Nest Hub Max has you covered. From hand gestures to a touchscreen interface that lets you control smart home devices like lights, locks or thermostats, the Nest Hub Max offers the best of both home control world – voice and touch.

AMAZON ECHO STUDIO

PRICE: £189.99
ASSISTANT: ALEXA
COLOURS: BLACK
SPEAKERS: 25MM TWEETER, THREE 51MM MID-RANGE SPEAKERS, 133MM WOOFER, 3.5MM/MINI-OPTIC LINE IN, DOLBY ATMOS
SIZE: 206 X 175 X 175MM, 3.5KG

BEST FOR SOUND QUALITY

Amazon's Echo Studio is an imposing, heavy speaker – you won't miss this on the coffee table. But if you want good sound and a genuinely smart, smart speaker, it is the best on offer at a jaw-droppingly good price. Most speakers this size and quality start a couple of hundred quid higher and don't have anywhere near its smarts.

The Studio packs a lot of high-end audio into that big frame, delivering superb 360° sound from its five speakers. Plus, it can do fancy things like sense the acoustics of your room for optimal playback, and then play 3D audio to make it sound like the drums are behind you and the singer is in front. We were particularly impressed at how well Alexa responded on the Studio, even when we had the speaker cranked to its impressively loud top volume.

What makes it stand out as a smart home speaker is the built-in Zigbee radio, which turns it into a smart home hub to which you can easily add devices like Philips Hue smart light bulbs, SmartThings motion sensors, and Amazon smart plugs – without needing any other hubs or devices to control them. Just plug them in, turn them on and your Echo Studio will automatically add them to your Alexa app. From here you can create fun and useful Routines, such as 'when motion is detected after dark, turn on my lights and start the kettle'.

IT'S A SLUG'S GAME

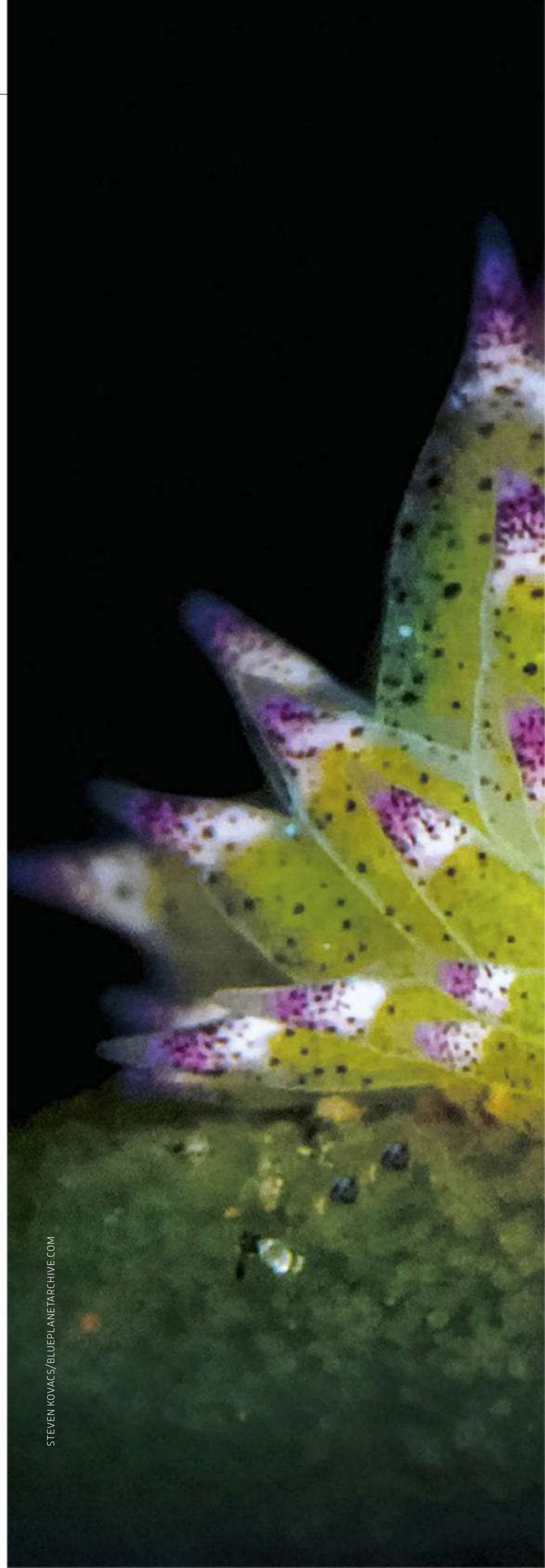
SEA SLUGS SPORT SOME OF NATURE'S MOST UNREAL ADAPTATIONS, INCLUDING SOLAR-POWERED SKIN AND DISPOSABLE PENISES. WELCOME TO THEIR WEIRD WORLD

WORDS: DR HELEN SCALES

SOLAR-POWERED SEA SLUG

It looks like a tiny, cartoon sheep, but this is in fact one of more than 4,700 known species of sea slug that creep and occasionally swim through the ocean. Known as the leaf sheep (*Costasiella kuroshimae*), this sea slug lives around coral reefs, where it grazes on clumps of algae. The green colouration comes directly from its food – a leaf sheep retains the algae's chloroplasts (tiny cellular structures that harness the Sun's energy to make sugars), and incorporates them into its skin, where they continue to photosynthesise. This trick of stealing chloroplasts, called 'kleptoplasty', stops the leaf sheep from starving when there's no food around. It's one of a range of weird and unique survival techniques that sea slugs have evolved.

The term 'sea slug' is applied to an assorted and flamboyant bunch of molluscs, all close relatives of snails that evolved a shell-free adult life. They are found almost anywhere in the sea, from rock pools to the deep sea, in tropical and temperate waters, and even in the Arctic and Antarctica.



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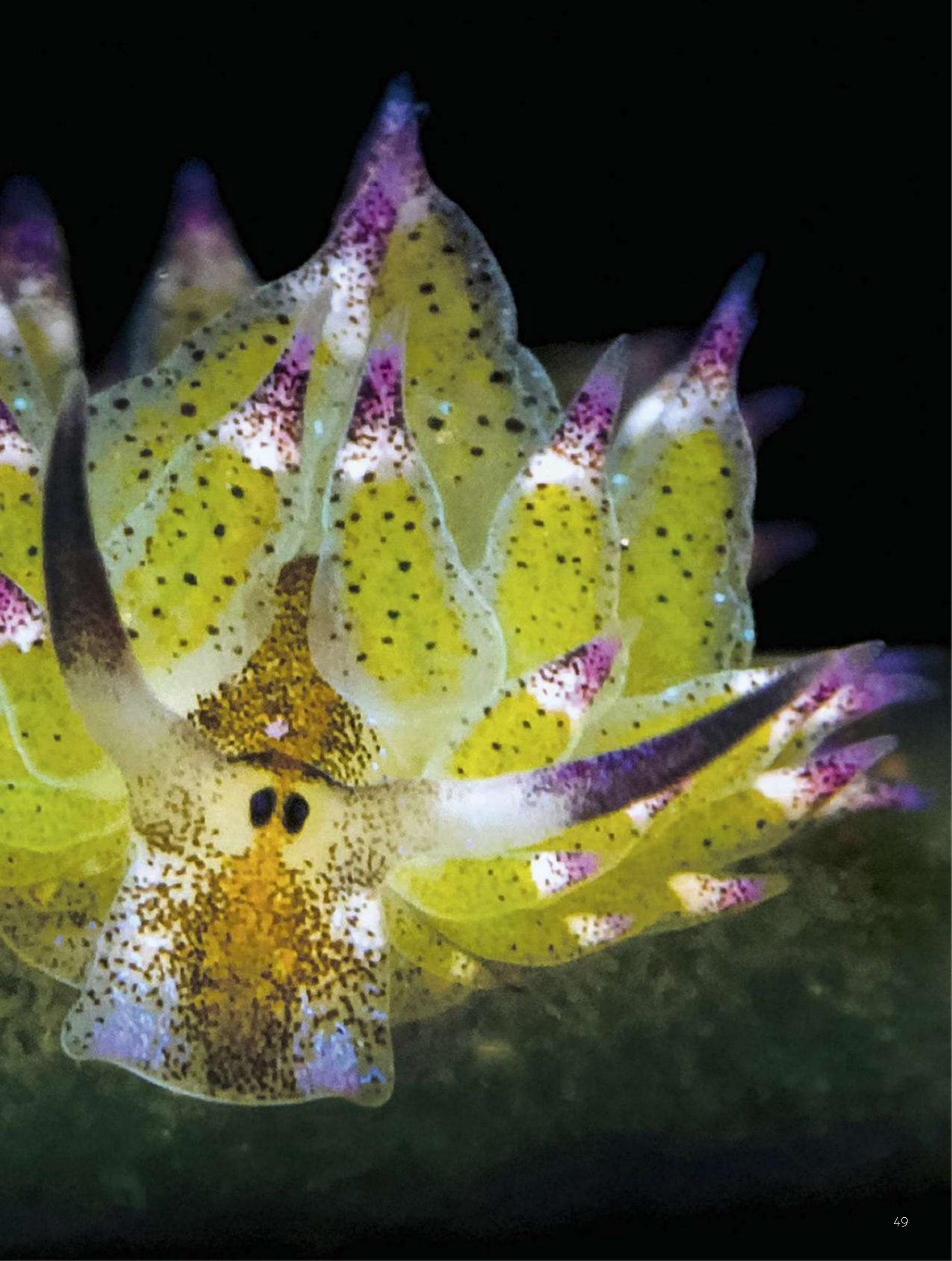

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MARVELLOUS MOLLUSCS

Sea slugs come in an amazing variety of colours and shapes. "The geometric beauty of them is startling," says Heather Buttivant, author of *Rock Pool: Extraordinary Encounters Between The Tides*, and an expert in finding sea slugs around the British coast. Many, including this tropical sea slug (*Cyerce nigricans*), are covered in projections called 'cerata'. When this species gets disturbed, perhaps by a hungry fish or crab, it jettisons some of its cerata, like a lizard dropping its tail, to distract the intruder, while it makes its escape.

Sea slugs follow chemical trails to find food and mates, 'tasting' the water with a pair of organs called 'rhinophores' that are located on their head. In this species, the rhinophores are forked like a snake's tongue, to help detect the direction a smell is coming from.

→

NEON CAMOUFLAGE

With no external shells to hide inside, sea slugs have evolved various ways to avoid getting eaten. The banana sea slug (*Notodoris minor*) is a coral reef-dweller, and its gaudy colour is camouflage: when crawling across a yellow sea sponge – its preferred food – it becomes hard to spot. On the other hand, the eye-catching patterns of many sea slugs warn predators to leave them alone because their bodies are filled with noxious chemicals. Some sea slugs produce toxins themselves; others obtain them from their food.

The banana sea slug belongs to a group of sea slugs, the dorids, which have a smooth outer layer and feathery gills sticking up from their backs. A second group, the aeolids, are slim and covered in finger-like cerata that act as gills. Dorids and aeolids are known as nudibranchs, meaning 'naked gill'.

MAGNUS LUNDGREN/WILD WONDERS OF CHINA/NATUREPL.COM, REINHARD DIRSCHERL/FLPA

WHEN SLUGS HUG

Sea slugs are what's known as 'simultaneous hermaphrodites'. Each individual has female and male sex organs, but they can't mate with themselves and have to swap sperm with another slug. The sea slug penis, shown in this close-up of a pair of mating sea slugs (*Nembrotha lineolata*), is located on the right side of the head, a hangover from the asymmetrical, twisted bodies of the coiling snails they evolved from.

Sea slug copulation can take anything from a few seconds to 10 minutes. Some species mate repeatedly using disposable penises: the first time a pair mates, each slug detaches its penis and within 24 hours grows a new one, subsequently mating a second time. Scientists think the first penis acts as a syringe, removing any sperm left by competitors that the slug previously mated with. A backup penis is coiled up inside both sea slugs, ready to be deployed.

↑ →

EGGS GALORE

After they've mated, sea slugs lay eggs. Some species lay a few at a time, while others lay thousands or millions, often in spiralling ribbons, like *Risbecia tryoni* (above), or sometimes in separate clutches, as *Knoutsodonta jannae* has done here (right). For sea slug spotters, the eggs can be the best way to find tiny and otherwise inconspicuous species. "They lay coils of spawn that are several times their own body size," says Buttivant.

The eggs can take a few days or weeks to hatch, either as mini sea slugs or more often as swimming larvae, called 'veligers', which have a tiny coiling shell. The veligers swim around until eventually, often triggered by chemicals wafting from their preferred food such as sponges, the larvae will abandon their shells, settle onto the seabed and transform into adult sea slugs.

ALEX MUSTARD/NATUREPL.COM X2, CONSTANTINOS PETRINOS/NATUREPL.COM

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A DANGEROUS MEAL

This sea slug (*Flabellina nobilis*) from the North Atlantic is feeding on the stinging tentacle of a flower-like hydroid (a relative of corals and jellyfish) without getting stung. Its mouth, throat and stomach are lined with the tough material chitin, and it also produces slime which stops the stinging cells from firing. The sea slug keeps the hydroid's unfired stings, which are like minute poison-tipped harpoons, and pushes them into sacs in its skin to use in its own defence against predators.

"Sea slugs look so delicate," says Buttivant, "but they actually have all sorts of defences." One species of sea slug that lives on British coasts will squirt sulphuric acid from its skin when attacked.

→

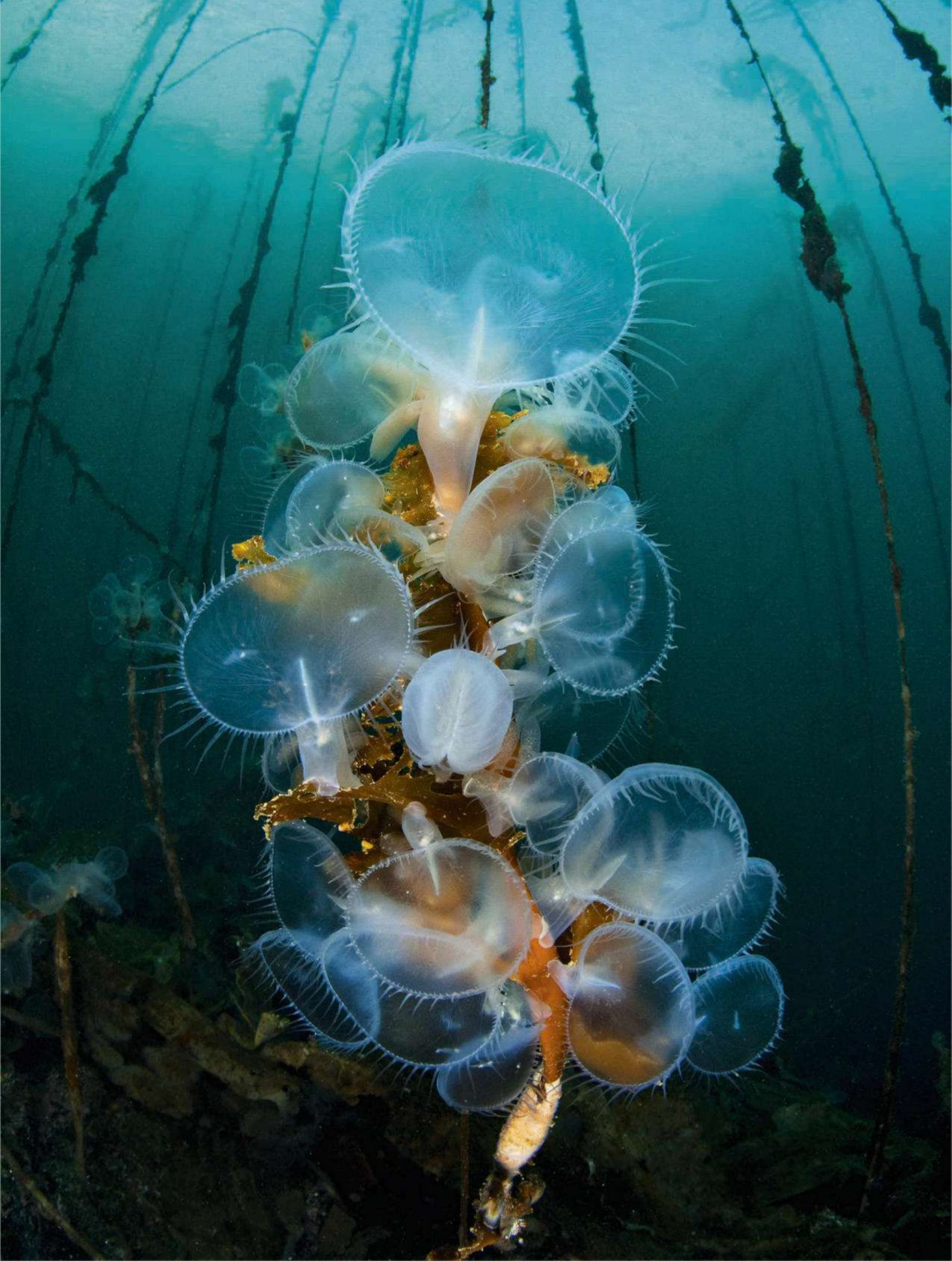
FEEDING FRENZY

The lion's mane nudibranch (*Melibe leonine*), is a sea slug like no other. Living in the kelp forests off the Pacific coast of North America, it has a spectacular, tentacle-fringed hood. To hunt, it grasps kelp fronds and sweeps its hood from side to side. When a tiny, planktonic animal swims past and touches the tentacles, the hood quickly closes and traps the prey. Lion's mane nudibranchs have a sweet smell, like watermelons, which deters predators and attracts mates.

Another species of plankton-eating sea slug (not shown) uses hydroids to help it hunt. It scoffs the hydroid, along with the plankton that the hydroid has just eaten – essentially getting two meals for the price of one. **SF**

by **DR HELEN SCALES**
(@helenscales)
Helen is a marine biologist, broadcaster and author. Her next book, *The Brilliant Abyss* (£16.99, Bloomsbury Sigma) will be out in February 2021.

ALEX MUSTARD/NATUREPL.COM X2



WHY (NEARLY) EVERYTHING YOU'VE BEEN TOLD ABOUT YOUR DIET IS WRONG

by PROF TIM SPECTOR

We all know that fat is bad for you and veganism is super-healthy, right? Not necessarily. Read on as we bust some of the biggest, most-enduring food myths...

ILLUSTRATION: MAGIC TORCH

60
70
80
50
90
40
100
30
110
20
120
Kg
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0
140

Global rates of obesity and related disease have increased in the 21st Century to epidemic proportions, despite the efforts of the health services, doctors and nutritionists. We are told that good health is about eating less and exercising more, but is it that simple? Science shows that we all have different metabolic responses to the same foods, so any guidelines will not work for all of us. Many diet recommendations are often based on poor, outdated or biased science.

We are all influenced by deeply ingrained or inherited myths about food (breakfast is the most important meal of the day, fat is bad, fish is good, and so on), and these can be hard to shake. In addition, the global food industry throws billions of dollars every year into manufacturing and marketing processed foods that some believe are designed to leave us wanting more.

There are many reasons for our deep misunderstanding about the science of food, not least that nutrition is an incredibly complex and a relatively new science. It only became a serious area of research in most countries in the 1970s, and it has long been sidelined in medicine. When I trained as a doctor, 40 years ago, nutrition was just an afterthought, and we learnt more about scurvy than diet and obesity. Sadly, this is still true today in medical schools. Good nutritional research is difficult and expensive to carry out, and it's not easy to secure funding for the large, long-term studies needed for reliable results.

Until recently, nutritional science also ignored the important role of microbes: the community of up to 100 trillion bacteria, fungi, parasites and viruses each of us carries in our guts, which outnumber the cells in our bodies. Food interacts with the different species of microbes to produce thousands of chemicals which affect our health. Understanding this process has changed the way we approach food and nutrition.

GETTY IMAGES, ALAMY

But there are many reasons to be hopeful. The science is improving at an unprecedented rate. The latest nutrition studies – including those from the Weizmann Institute of Science in Israel, and our PREDICT studies in the UK and USA – use new advances in artificial intelligence and citizen science, and are changing core beliefs.

We can now prove that there is no one-size-fits-all perfect diet. Diversity in our diet is the key to maintaining a healthy microbe population and good health. Conditions such as diabetes can be controlled with low-carbohydrate and high-fat diets, disproving the long-held belief that only medication could keep the disease at bay. Fat – for years considered the evil of nutrition – is now shown to protect against heart disease and diabetes, not the reverse.

We urgently need to reassess what we think we know about food, and unlearn the myths that have misled us for far too long.

CALORIE COUNTING

Calories in equals calories out – this simple rubric has built a diet industry. According to international guidelines from the World Health Organization (WHO), adult males should consume 2,500 calories a day, and females should consume 2,000. But I believe any universal recommended daily calorie intake is at best misleading, and at worst harmful.

The general misconception is that calories are a direct or even remotely precise measurement of how fattening a food is. In fact, although we can accurately measure the calorific value of a meal, the relationship between those calories and our individual bodies is less straightforward. Each of us has a different basal metabolic rate (which can vary by up to 25 per cent in normal, healthy people), and we all burn up energy in different ways.

We also have to remember that all calorie counts are based on estimates. The idea that we can precisely measure the energy value of any food is nonsense, and claiming one dish with 312 calories is better than one with 329 is laughable. Walnuts, for example, spent years with their calorie content inflated by 20 per cent until it was discovered that much of the fat they contain is not released when we eat them. How the body uses and stores the energy gained from, say, corn on the cob is very different from cornbread or cornflakes. Yet the simplistic calorie-intake theory treats the energy gained from each the same.

We also now know that the way food is cooked alters its structure: so a steak tartare will provide fewer calories than a burger cooked rare, which will provide fewer than a well-done charred one. Even more importantly, ultra-processing of food destroys the complex structure of the plant and animal cells, turning the food into a nutritionally empty mush. The average person in the UK actually consumes slightly fewer calories per day than in 1976, but many more of those calories come from ultra-processed food.

The biggest problem with the calorie is not the measurement itself – which does serve some crude purpose – but the way it has given us a false sense of security and precision. The calorie has enabled the food industry to market unhealthy 'low-calorie' foods as healthy, and allowed health regulators to show something quantifiable. But the calorie has been a disaster for the average consumer. We have been fooled into thinking that the effect of food can be easily measured, and conned into eating highly processed foods that fail to satisfy our hunger. We're not cars with a standard fuel gauge; we are far more complex and intricate, and rather than basing our decisions about what to eat on a universal, arbitrary and often inaccurate number, we need to learn to understand our own bodies and what they need.

"We have to remember that all calorie counts are based on estimates. The idea that we can precisely measure the energy value of any food is nonsense, and claiming one dish with 312 calories is better than one with 329 is laughable"

2 VEGANISM IS THE HEALTHIEST WAY TO EAT

Plant-based diets have become fashionable in recent years. The number of vegans in the UK has quadrupled between 2014 and 2019, with purported benefits for our health, as well as for animal welfare and the environment.

Veganism is good news for other animals and for the environment. But in terms of health benefits, the science is not so clear. Although some studies show that plant-based diets appear to lower the risk of cardiovascular disease, this does not increase the lifespan of vegans compared to non-vegans. A UK study that analysed 5,200 deaths found vegetarians and non-vegetarians had similar death rates.

Although vegans can get all the protein they need from pulses and grains, they do tend to suffer from reduced levels of vitamin B12 and iron. Children who are brought up as vegan are often smaller and have low levels of certain key nutrients.

The food industry has latched on to the popularity of veganism, producing many plant-based alternatives. They are often highly processed and full of salt, sugar and preservatives – one 'vegan fish finger' I looked at contained 40 artificial ingredients.

The most positive feature of any vegan diet is the high consumption of plants, which are essential for good health, providing high levels of the fibre that's beloved by our microbes. But plants can be added to vegetarian or meat-eating diets to obtain the same benefits. So, we cannot say that veganism *per se* is healthier.

There are many compelling reasons to consider lowering your intake of meat and dairy. Most people don't require as much protein as we are led to believe, and our planet's future depends on us all eating less meat. Just don't be fooled into thinking that vegan is a byword for healthy.

GETTY IMAGES X2, ALAMY

3 LOCAL IS ALWAYS BEST

In the US, the average food product travels 1,500 miles (2,414km) before it reaches a consumer's plate. Britain once produced the most varieties of apples in the world, we now import 70 per cent, with some travelling over 10,000 miles (16,090km).

There are huge environmental, social and economic costs associated with transporting food around the world, and many people are rightly concerned about reducing food miles. Conscientious consumers try to buy their food locally in an attempt to counteract some of this damage, helping the environment, economy and producers. This sounds simple and can only be a good thing, surely?

The reality is more complicated. A study published in *Semantic Scholar* in 2009 found that eating lamb from New Zealand is a more environmentally friendly option for most of us in the UK than more locally produced Welsh lamb. Although the meat travels a long way, it does so in great quantities, and the lambs are reared in eco-efficient farms that use hydroelectricity. A slightly better climate means that grass grows for longer, so the sheep can roam and need less additional feed.

Tomatoes from Spain's sunny climate are more sustainable than

FOOD FACT

Most Westerners consume fewer than 50 plant and animal species

those produced in heated greenhouses in the UK.

Of the estimated 30 billion food miles associated with UK-consumed food, 82 per cent are generated within the country, and over half of these in 2005 were simply due to car trips from homes to local food shops. So buying your food locally may reduce the distance travelled from field to fork, but any environmental benefits are likely offset by multiple trips of less efficient, petrol-guzzling vehicles.

Still, there is no doubt that eating locally can be best when we produce seasonally and choose our collection and delivery transport methods wisely. Locally may be best, but not always, and just make sure you know where it comes from, it is seasonally produced and minimally processed.

4

YOU NEED EIGHT GLASSES OF WATER A DAY

We all need water to thrive, but the general recommendation has been to drink more and more, with many guidelines now advising a minimum of eight glasses a day. Is there any evidence behind this recent concern about our going thirsty and drying up? The short answer is no. Studies looking at intakes over 10 years in the elderly failed to show any benefits of extra water on kidney function or mortality.

Clever marketing from bottled water companies has not only convinced us that we need to drink more water, but also that expensive bottled mineral water is somehow better for us. We now drink more bottled water than ever before, with the global industry growing rapidly at 10 per cent a year. By 2025, the global market is estimated to be worth $215bn (£167bn approx). But research shows that tap water nowadays is perfectly safe, and with added fluoride it is also good for our teeth. There have been studies showing that tap water contains traces of common pharmaceutical drugs, but they have also found the same levels when testing bottled water. Although water in many areas contains chemicals, such as chlorine (a natural gas that quickly evaporates from water once added), the levels are too small to make a noticeable difference to our health.

“Bottled water has devastating environmental costs, and no proven health benefits”

Bottled water has devastating environmental costs, and no proven health benefits, but does it taste better? Probably not. Blind tastings have even shown that tap water scores higher than most mineral waters. My advice is stick with tap water: you will be reducing the global environmental cost of half a trillion plastic bottles piling up each year and taking a stand against the power of marketing.

5 WE SHOULD ALL FOLLOW THE SAME DIET GUIDELINES

For the last 50 years we have been told exactly the amount of calories, fat, protein and carbs we need to eat to be healthy. We are currently told to avoid saturated fats, pick low fat foods, select margarine over butter and eat plenty of starchy vegetables. We are told to eat little and often and never skip breakfast. There is no good science to support any of these recommendations, and recent science has disproved many of them. So it is no surprise we have tripled the levels of obesity over this time.

As well as the influence of the food industry, the one thing we have overlooked is that we are all unique. When we gave 1,000 people identical meals in the 2020 PREDICT 1 study and checked their blood, metabolic and inflammation responses, no two people were the same. In our study, even identical twins (who are genetic clones) had different responses. Some people respond badly to fats, others to carbs, and these short-term blood responses can lead to weight gain and metabolic problems. Recent randomised trials of diet like the 2018 DIETFITS study compared high-fat and low-fat diets and found no difference after a year, but huge differences within the groups. We are now in the era of personalised nutrition where most of these outdated diet guidelines can be consigned to history.

We can now measure food responses in real time with glucose monitors, and check fat levels with home blood tests. Meanwhile, testing your gut microbes offers a good prediction of your likely responses to different foods. It's important to realise you are unique. Listen more to your body, and less to outdated dogma. Try experimenting with different foods, meal timings and maybe intermittent fasting and see how you feel. If you eat a wide variety of plants and aim to keep your gut microbes happy, you can't go far wrong.

6 EXERCISE WILL MAKE YOU THIN

I am a big fan of exercise. I enjoy cycling or swimming most days and it undoubtedly makes you healthier and reduces many common diseases. But it is not the weight-loss cure that it is cracked up to be. Unless you are a professional athlete or regularly running marathons, the chances are that exercise will reset your metabolic thermostat downwards and your hunger levels will increase, you will eat more and subsequently burn less of the calories than you would if you were resting. The soft drinks companies in particular have been driving this myth for decades, by funding science suggesting that if only we exercised more we could drink as many sugary drinks and snacks as we wanted. The plain truth is that, for most people, you can't run off a bad diet and good food choices are more important than gym membership.

7 PESTICIDES DON'T HARM YOU

GETTY IMAGES X3

The modern production of cheaper food in greater quantities has been facilitated by pesticides. Most food products you consume regularly will have been exposed to the chemical glyphosate. Breakfast foods such as porridge oats have been shown to have especially high levels. This pesticide has been used by farmers since 1974 due to its ability to kill weeds while preserving and drying out the crops and, supposedly, without harming animals or humans. Some studies show, however, that there may be a correlation between exposure to this chemical and a rise in certain blood cancers (lymphomas), with side effects increasing when we look at other pesticides such as organophosphates.

This data is disputed by the multinational companies who produce glyphosate as well as by some health agencies. What is less disputed is the damage pesticides (and herbicides) inflict on the microbial populations living in the soil and in our guts. One of the roles of our microbes is to stabilise our immune system, so it is perhaps no surprise that some epidemiological evidence (although weak) links pesticides to increased rates of allergic disorders. Although government bodies reassure us that the levels of chemicals used in farming are safe for our health, we are now eating these chemicals for all of our lives. Particularly vulnerable to subtle effects may be pregnant women and their infants. Further and more robust studies are urgently needed to look at the effects on our microbe populations.

In the meantime, we can try to reduce exposure by washing our vegetables and fruit, growing our own, or favouring organic ingredients, which certainly have a lower exposure levels. SF

by **PROF TIM SPECTOR** *(@timspector)*
Tim is a professor of genetic epidemiology at King's College London. He is lead investigator of the COVID Symptom Study *app. His latest book is* Spoon-Fed: Why Nearly Everything We Have Been Taught About Food Is Wrong *(£12.99, Jonathan Cape).*

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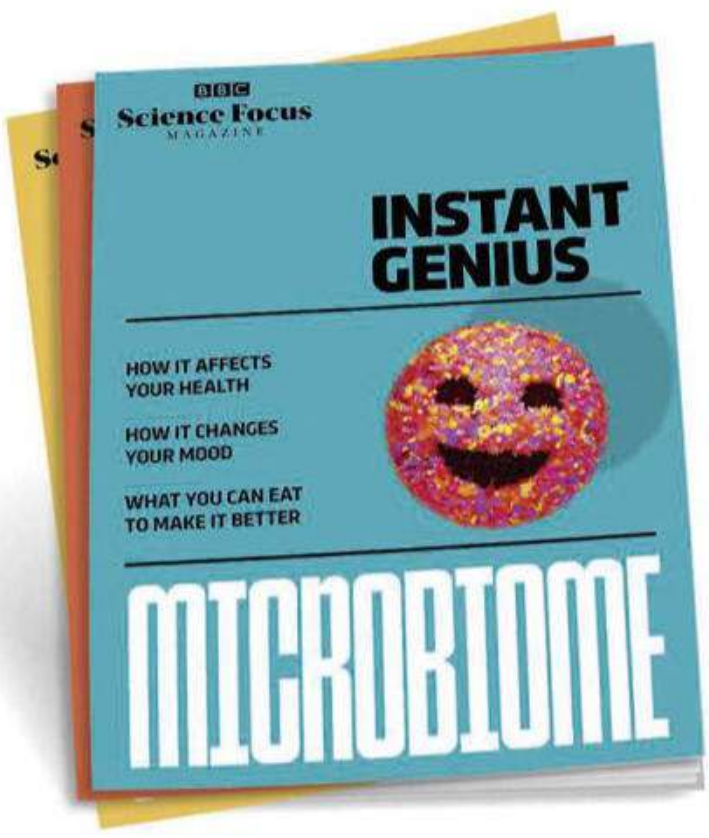

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COMMENT

BATTLING THE WINTER BLUES

Many of us suffer from low mood when the nights draw in, but take heart: there are some easy ways feel better

According to the Danish writer Henrik Nordbrandt, there are 16 months: "November, December, January, February, March, April, May, June, July, August, September, October, November, November, November, November."

November is long and miserable. The clocks have gone back, the days are shorter, and it's cold and damp. This year, looming over everything else, is the threat of COVID-19.

What I find particularly difficult about the shorter days is that I am part of the roughly 10 per cent of the British population who suffer from seasonal affective disorder (SAD). Like most people with SAD, I get more gloomy and introspective as the winter wears on. I sleep badly, find it harder to get motivated and develop a serious craving for sugary carbs. You may be thinking, "Who doesn't?" but there is evidence that people with SAD have, during the winter months, higher than normal levels of something called SERT (a serotonin-transporting protein). Higher levels of SERT mean lower levels of serotonin, a neurotransmitter linked to feelings of wellbeing and happiness. That could explain why, in winter, SAD people feel so low.

A few years ago, while making a film about SAD for *Trust Me, I'm A Doctor*, I met Anna Wirz-Justice, professor emeritus at the Centre for Chronobiology at the University of Basel, Switzerland. She told me that, in winter, lack of exposure to daylight can throw our biological rhythms out of sync, which leads to the kind of symptoms that characterise 'the winter blues' or SAD.

"In winter, lack of exposure to daylight can throw our biological rhythms out of sync"

So I bought a light box, which sits beside my computer and bathes me in 10,000 lux of bright white light for an hour or so in the mornings while I sit tapping away. I also go on early walks with our dog, since exercise outdoors in the morning light seems to be particularly effective at reducing the impact of SAD.

Beyond that, I'd also recommend switching your diet to something richer in fish and fibre. A few years ago, scientists from the Food and Mood Centre in Melbourne carried out the SMILEs study, which involved randomly allocating 67 patients with moderate or severe depression, most of whom were on medication or having psychotherapy, to either a Mediterranean-style diet or 'social support'. Those in the diet group were asked to eat more vegetables, fruits, nuts, eggs, fish and olive oil. They were asked to drink red wine, rather than beer or spirits, and to cut back on sweets, refined cereals, fried food, fast food, processed meats and sugary drinks.

There were impressive differences between the groups after 12 weeks, with those on the Mediterranean diet getting much lower scores for depression and anxiety. In fact, 32 per cent of those on the Med diet went into remission (no longer 'depressed'). Those who stuck closest to the Mediterranean diet enjoyed the biggest improvement in mood, so it is certainly worth giving it a go. SF

MICHAEL MOSLEY

Michael is a writer and broadcaster, who presents *Trust Me, I'm A Doctor.* His latest book is *Fast Asleep* (£9.99, Short Books).

BBC TWO

PORTRAIT: KATE COPELAND ILLUSTRATION: JASON RAISH

COMMENT

ON THE CONTRARY...

We might be craving more face-to-face interaction, but psychology has shown that virtual contact is just as good... or even better

Research is most exciting when it throws up something contrary to popular belief. My field, psychology, has a reputation for finding things that confirm what we already know about ourselves – behaviour like preferring to hang out with people who are like us, or trusting someone we believe is credible – and maybe that's why people like it. But when science comes out with something unexpected, like the famous finding that logical and respectable people will do terrible things to other humans when in the presence of a commanding authority, that's when things get interesting.

The internet is full of these funny contradictions. For example, who would have thought that you can feel a real and important connection with someone you've never met in the flesh? Many people believe that the internet is a paradox, as Robert Kraut and his colleagues found in 1998 in their paper: 'Internet paradox: a social technology that reduces social involvement and psychological wellbeing'. But it's not. I know this from the opposite effects described by the 12 years of research that followed, including from Kraut and his colleagues in a later study published in 2002. But as we know from the bleeding obvious (and lots of psychology studies), we would rather hear something that confirms what we believe.

ALEKS KROTOSKI

Aleks is a social psychologist, broadcaster and journalist. She presents *The Digital Human*.

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"Online, we have a lot more connections who are willing to give us a boost"

Now, here we are in the midst of a remarkable moment in internet history, as more people than ever grapple with truly living online. As I've said in the past, this enforced digital experiment is exposing the boundaries of what modern tech is able to offer human interaction, and where it fails. After such a long time of being mediated, we are hungry for face-to-face contact. We also prefer research that reminds us how essential it is in social involvement and psychological wellbeing. Well, I'm going to be contradictory here.

In a recent issue of the *Journal Of Computer-Mediated Communication*, an international team of scientists wanted to find out what helped people cope during stressful situations: face-to-face or online interactions. They looked for psychological and biological markers of stress response in 469 students in Chile who were preparing to take a crucial university placement exam. And what they found... you know where this is going... is that online support fared better than face-to-face.

Now, this finding might be an artefact of age, or the context. I doubt anyone who's suffered a loss over the last few months would prefer a virtual fist bump over a real one. But what the results of this study do show is that we are better able to cope with stress when we experience more support. And online, we have a lot more connections who are willing to give us a boost. So when you think about it, the results aren't contradictory at all.

A mediating machine doesn't mean the death of humanity. It just makes the relationship more, well, complicated. Every contrary finding gives us a glimpse at something that is obvious when you think about it. And isn't it always more fun to learn something new? SF

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THE PUZZLE OF A PERSON

Forensic anthropologist **Prof Dame Sue Black** talks to **Amy Barrett** about what it's like to dissect a human body, how a single bone can tell a whole story, and the ways in which we can identify perpetrators from the backs of their hands

WHAT WAS IT LIKE, THE FIRST TIME YOU WORKED WITH HUMAN REMAINS?

The first time I worked with human remains was in the dissecting room in Aberdeen University. I would have been 18 or 19 at the time. You walked into this room, a huge room that was almost like a conservatory because it had a glass ceiling and opaque glass windows all the way around. It had the most beautiful parquet flooring. It was a really strange room.

There were around 50 metal tables, on top of each was obviously a body, each one covered in a white cotton sheet. So, when you walked into the room, all you saw were these white mounds in rows and lines along the room. The next thing you do is you take off the white sheet and you're faced with the dead. You have to touch them, and you feel really embarrassed about touching. This is somebody else's body, who's dead.

Then they expect you to put a blade onto a scalpel handle. And no one tells you how to do that. You always end up slicing your fingers. And then you have to make that first cut. It's something you never forget. It's a Rubicon that you can only cross once.

CAN YOU TELL US A BIT ABOUT YOUR NEW BOOK, *WRITTEN IN BONE*?

One of my areas of expertise is in criminal dismemberments. They [the publishers] asked me to take each section of the body as a chapter, and [imagine] that was the only section of the body available to me in a criminal dismemberment, and to say what I would be able to tell from that section of the body. I was able to use some of my case histories, to show cases where, in fact, that part of the body had been particularly important in the investigation, or the identification of the person or whatever it may have been.

WHAT IS CRIMINAL DISMEMBERMENT?

Criminal dismemberment is the criminal act ▶

PROF SUE BLACK

Prof Dame Sue Black is an anatomist and forensic anthropologist. She is currently the Pro-Vice Chancellor for Engagement at Lancaster University. Over the course of her career, Sue has worked with the UK Foreign and Commonwealth Office and the United Nations, helping to identify victims and perpetrators from their body parts. Her first book, *All That Remains*, was a *Sunday Times* bestseller. Her new book, *Written In Bone*, is a fascinating and gripping account of the stories that each of our body parts can tell, long after we have passed away.

JANICE AITKEN

of reducing an intact human body into specific pieces. It is a rare crime and we maybe have three or four cases in the UK in a year where a body will have been dismembered.

Put your imagination on. You've just murdered somebody. Most people don't expect or intend to murder someone. It often happens as a result of a heated event, too much alcohol, drugs, a fight, whatever it may be, and somebody loses their life. At that point, when that happens, you're faced with a dilemma. What do you do? You would like to think all of us would go to pick up the phone to the police, to the emergency services and say, this is what I've done. But not everybody does. Some people go into a panic and run away, and the body will be left for somebody else to find. Or, they will think, 'I need to get rid of the body, I need to hide it.'

A whole body, especially of an adult, is a heavy and unwieldy thing. So, what they may think is, 'I can reduce that body into pieces, then I can get rid of the pieces more easily.' Most dismemberment is about transportation of the remains for dumping it. For some, it's about disfigurement, a way to take off the features of an individual so that it will make it more difficult for them to be recognised. But of course, now with DNA, that's less of a reason to do it than it perhaps was in the past.

IF WE FIND BODY PARTS, WHAT CAN WE TELL FROM THEM THAT WILL START THE CRIMINAL INVESTIGATION?

What you have in front of you are parts of a human jigsaw. It's your job to try and piece them together so that you can create the story of what happened to the individual, but more importantly, from the field of forensic anthropology, who they were when they were alive. If you're certain it's human, the question will be: how long has the individual been dead? If the body is intact or still fleshed, then you know that question isn't so important. But if these are fragments of bone, it becomes very important, because technically they could be archaeological. And if these bone fragments are hundreds of years old, you're not going to set up a murder investigation.

IF THE BODY PART IS STILL FLESHED, WHAT CAN YOU TELL FROM ITS LIMBS?

One of the cases that I talk about in my new book was known as the 'limbs in the loch' case.

There are police divers that train off a particular pier on Loch Lomond, and one day they found a collection of black plastic bags at the bottom of the loch. They picked them up thinking that it was material put in there for them to train. When they opened up the plastic bags, they realised that they were actually looking at human limbs that had been severed. This wasn't a training exercise at all. It was an actual case.

From the bones, you could tell whether the individual was adult or not – he was an adult, but a young adult. We could tell if it was male or female because there was very extensive hair patterning on the skin that you are highly unlikely to have on the thigh, for example, of a female. We could calculate what his foot size and shoe size was, and from there calculate the length of the leg, and then his height. The skin told us something about his ancestry. So very quickly, what we had was a young adult male, probably late teens or early 20s, around six foot in height, and white.

"To harness that power of science, to ensure that the right people are put on the right side of the bars, is important for health and wellbeing"

ABOVE Prof Sue Black's forensic expertise has taken her to Iraq, Sierra Leone and Grenada, and she also assisted in victim identification in the aftermath of the 2004 Indian Ocean earthquake and tsunami

ABOVE RIGHT Prof Sue Black has helped develop ways to identify criminals, using the creases and vein patterns on their hands

The police always say you need four things: age, sex, ancestry and height. They can then consult the missing persons list, to see if there's anybody in the area who fits that profile. Once you know who the individual is, then you can really start to investigate the surroundings associated with their death.

IS TECHNOLOGY AFFECTING YOUR JOB, OR WILL IT ALWAYS REMAIN VERY HANDS-ON?

Tech has helped when it comes to the other side of work that I do, which is identification of individuals from images. These images are usually of child sexual abuse, and the part of the perpetrator that is in that image is often the back of their hand. We've been doing a lot of research, from an anatomical perspective, on how to identify perpetrators from the backs of their hands. The pattern of superficial veins on the back of your right hand will be different to your left, and they'll be different between identical twins. If you look at the pattern of skin creases across the knuckles of your fingers, they're different on each one. If you have freckles or birthmarks or moles, they too will be in different places. There are all sorts of pieces of anatomical clues wrapped up in the back of your hand.

We've been working on this for about 16 years now. We've helped the police to secure about 30 life sentences and about 400 years of prison sentencing.

The next stage is in relation to AI and machine learning. So, when the police download images from somebody's phone or computer, they may have hundreds of thousands of images. It's not possible for us to go through them all. But we can train a computer to find a hand in an image, and if you can find a hand, what's the vein pattern? What's the knuckle crease pattern?

You then have a pattern for that individual. You create an algorithm, and you can then run that algorithm through the database of hundreds, thousands and sometimes even millions of police images and say, does this person appear in any other images? And if they do, then what you can start to do, hopefully, is connect cases that you weren't able to connect before.

THAT'S INCREDIBLE.

Science is cool! You know, many of the problems of the world, if not all, have got some form of a solution in a bit of science. To be able to harness that power of science to make things better, to ensure that the right people are put on the right side of the bars, is all incredibly important for health and wellbeing, not just of a person, but of a community and of a nation.

Science has just got so much to offer and so many questions not yet answered. Isn't that the most exciting detective investigation ever? SF

DISCOVER MORE

READ
Written In Bone *(£18.99, Doubleday) is out now.*

ON THE PODCAST *Listen to our full interview with Prof Sue Black on the* Science Focus Podcast.

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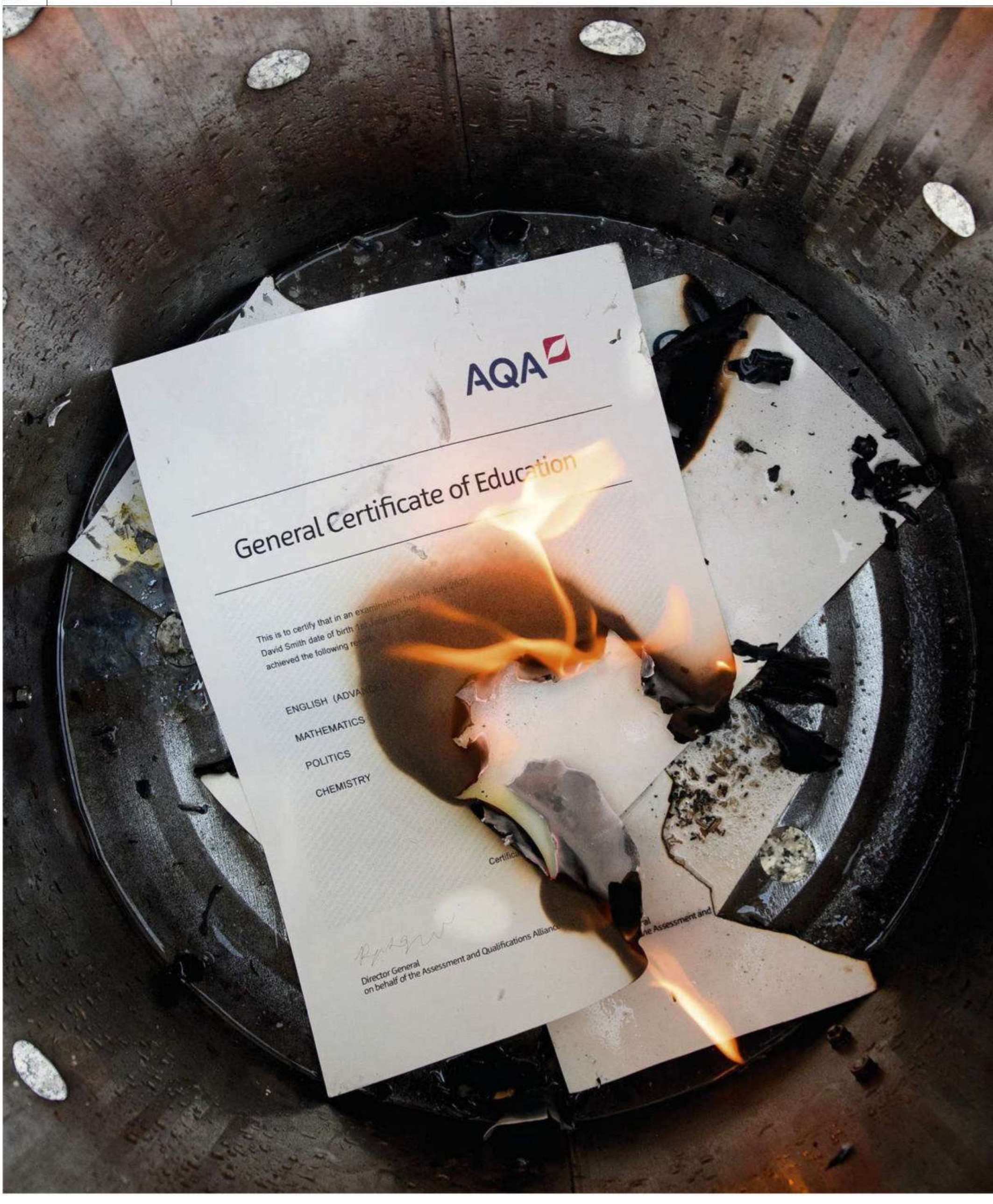
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WHY ALGORITHMS AREN'T MAKING THE GRADE

The recent controversy surrounding UK A-Level results highlighted the pitfalls of using algorithms to make our decisions for us. What went wrong and what should we be doing better?

WORDS: TIMANDRA HARKNESS

SHUTTERSTOCK

When the UK government decided to cancel school exams due to the coronavirus pandemic, they gave examination regulators Ofqual a challenge: allocate grades to students anyway, and make sure the grades given out this year are equivalent in standard to previous years. Ofqual's solution was to create an algorithm – a computer program designed to predict what grades the students would have received if they had taken exams.

Unfortunately, when the computer-generated grades were issued, 40 per cent of A-Level students got lower grades than their teachers had predicted. Some of them several grades lower. Promised university places were withdrawn. Lawyers offered to take legal action against Ofqual. Angry teenagers took to the streets with placards saying 'F**k the algorithm'.

Worse, students at large state schools seemed to have lost out more than those at private schools or those studying less popular subjects like classics and law. Faced with such glaring unfairness, the education minister announced that teacher predictions would be accepted after all, but not before universities had filled places on their courses, leaving everyone scrambling to sort out revised offers and over-subscribed courses.

Prime minister Boris Johnson called it a "mutant algorithm", as if the computer program had somehow evolved evil powers to wreck teenagers' aspirations. But in fact, Ofqual's program did exactly what it was ➤

designed to do. You might have expected the algorithm to start with teachers' predictions, as they know each student best. But no, any information about each individual student played a minimal role. Teacher predictions, mock exam results and GCSE results were only used when the number of students taking a subject in a school was small – under 15 in most cases. For larger groups, that data was only used to compare the whole group to the school's results in the previous three years.

Ofqual was instructed to make this year's overall pattern of results equivalent to previous years' results, to avoid 'grade inflation', and that is what they did. They took an average of each school's results in the past three years to give an expected spread of that school's results for this year: how many A*s, As, Bs, and so on.

Next, they used the past performance of this year's group, compared to previous years, to adjust for any improvement or decline in school performance. But they also adjusted to keep the national distribution of grades similar to the past. That gave the allocation of grades for this year's subject group. Then, to decide which student got which grade, each school was asked to rank each pupil from best to worst in each subject. The grades were dished out in rank order from best to worst.

FAIR AND SQUARE?

Was Ofqual's algorithm fair? Well, that depends how you define fair. Ofqual went to great lengths to check that no protected group would do worse under the algorithm than in exam years. Boys, deprived socioeconomic groups, different ethnic groups, all had similar outcomes to previous years, as a category. So why did state school students do worse than private school students?

In years where they take exams, state school students are more likely to be marked down from their teachers' predictions. They're statistically less likely to get the highest grades than private schools, which you may put down to poorer resources, lower aspirations from parents or teachers, or a combination of factors. Whatever the reason, many of those protesting that the algorithm robbed them of their future may have been equally disappointed by the results of their

"The algorithm had already decided that your school is a better guide to your potential than anything you do yourself"

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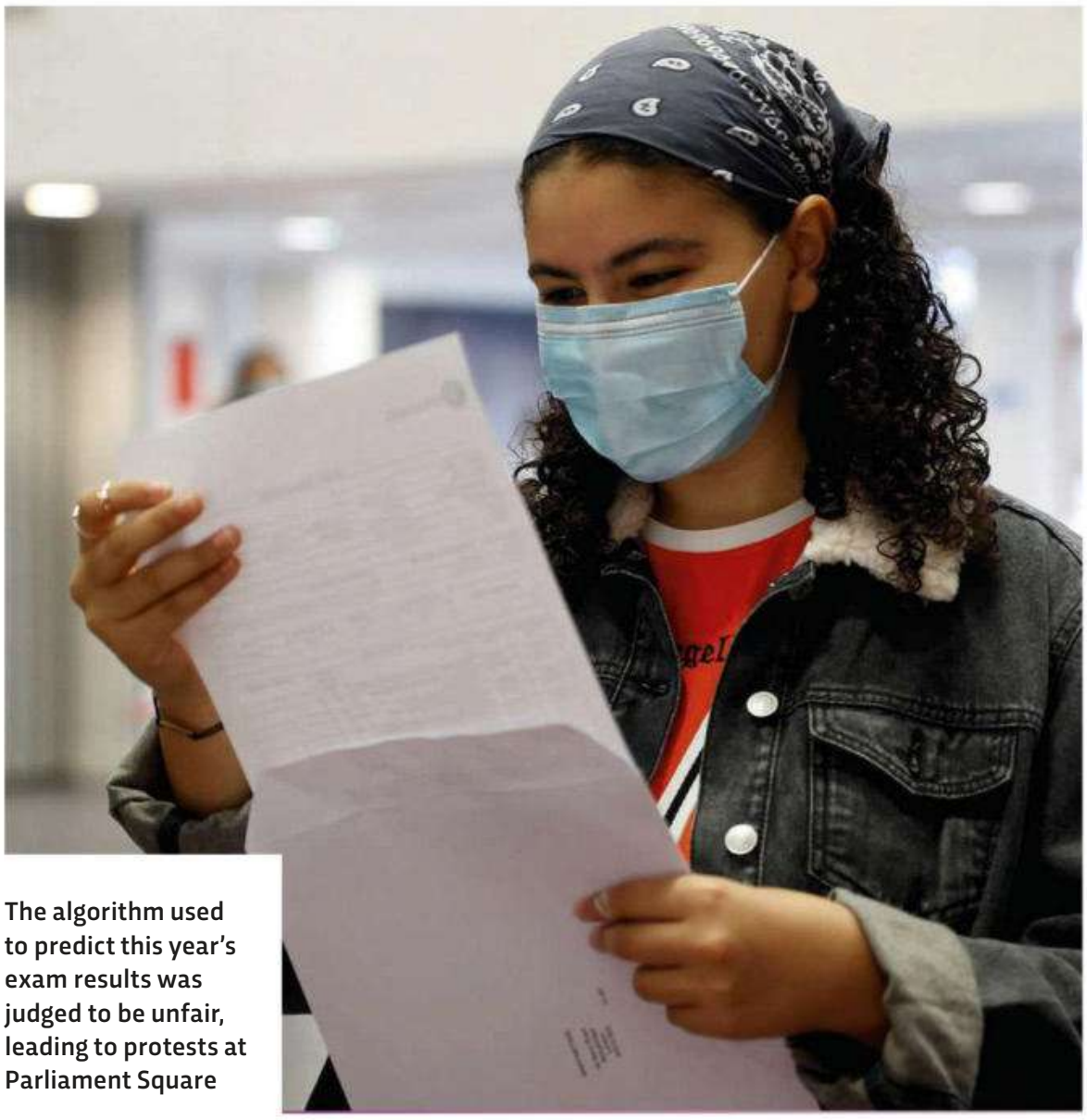


The algorithm used to predict this year's exam results was judged to be unfair, leading to protests at Parliament Square

own exam performance. But at least they would have had the chance to show what they could do under pressure. This year's students were doomed in advance, their attainments capped by what other students before them had achieved. The algorithm had already decided that your school is a better guide to your potential than anything you do yourself.

This illustrates two problems with algorithms. Their projections are based the past, which means the predicted future will, by default, look like the past. And though they are often good at population-scale prediction, that doesn't mean those predictions can or should be used for individuals.

Algorithms never predict the future. Humans predict the future, using projections made by machines. It was humans who wrote a program to find the patterns in data collected over time, and then asked it the question, 'If these patterns continue, what does the future look like?'

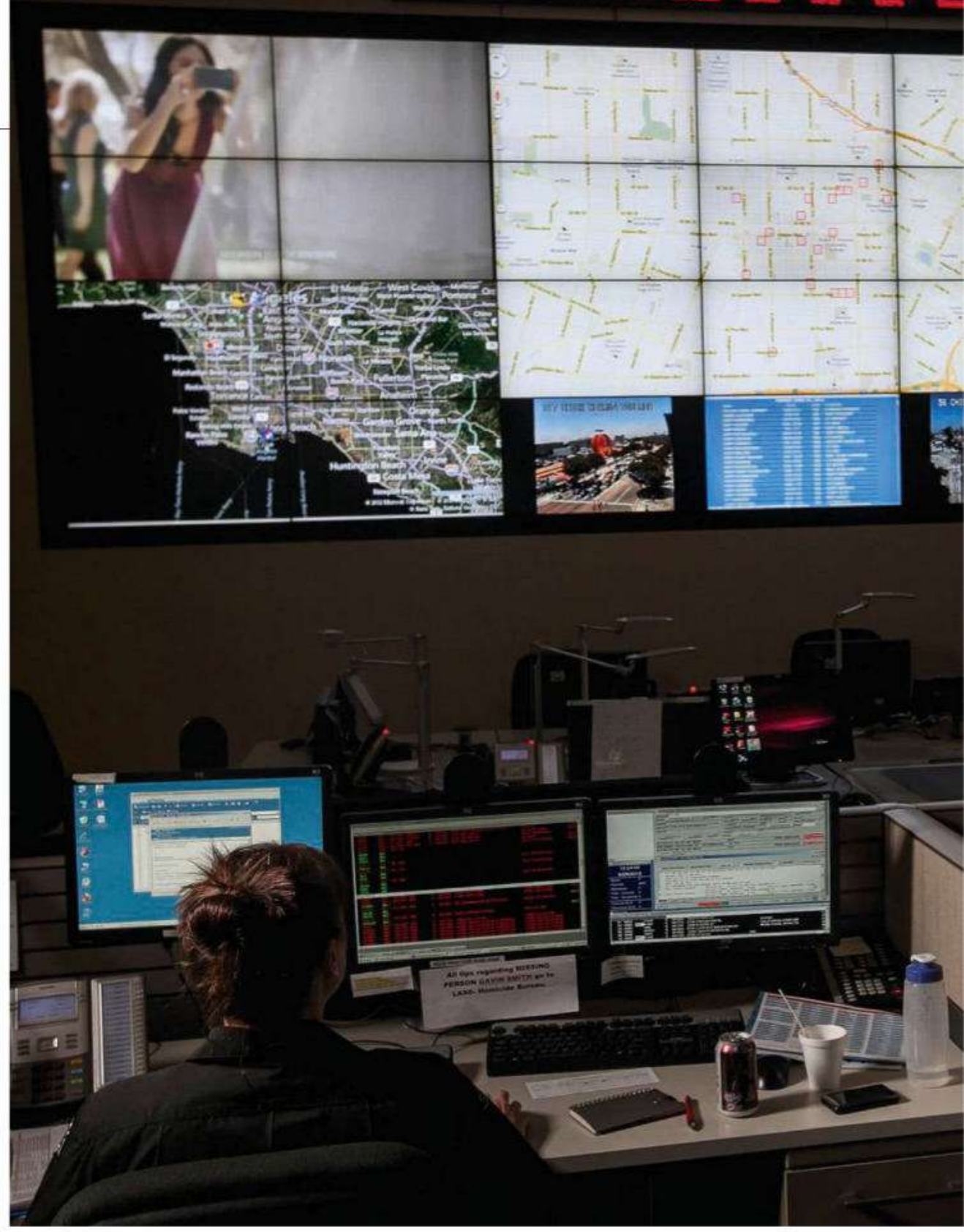
Much of the time, this works well. Patterns of traffic flow, for example, repeat themselves daily and weekly. Other factors that change that regular pattern, like school holidays or special events, can be programmed into the algorithm. So can long-term trends, like an increasing population, or more reliance on deliveries from internet shopping. Each of these decisions is an act of human judgment, based on both evidence and imagination. You could track trends in spending, combined with surveys about people intending to buy more online, and decide that delivery van traffic will go up. But you might also decide to collect data on how much people are driving to the shops, and conclude that reduction in car journeys will offset increased van traffic.

What data you include or exclude from your mathematical model is just as important as the type of computer program you choose to process it. But you can't collect data from the future. In that way, algorithms are exactly like the real world: the future will only be different from the past if humans decide to make it different.

Algorithms, especially machine-learning algorithms, which is what's usually meant by AI, are good at finding patterns in large amounts of data. Better than humans, in many ways, because they can handle more information ➲

and not be distracted by prior assumptions. That's why they're so useful in information-rich problems, like spotting abnormalities in medical scans that could be an early symptom of disease. What they can't do is understand the real-world context of a task, which means they're bad at causality. An algorithm may find that one thing, studying physics, for example, predicts another thing – being a boy. But that's a prediction in the statistical sense. It means that if you pick an A-Level physics student at random, four times out of five you will find a boy. It certainly doesn't mean that a girl can't study physics. But it does mean that if you picked a random boy and girl out of a sixth form, the boy would be more likely to be studying physics than the girl.

On an individual level, though, such predictions are inaccurate and unjust. All the science subjects together account for only one in five A-Level entries, so it's most likely that neither of our randomly picked students is studying physics. To take a more extreme example, 9 out of 10 murderers are men so, statistically, being a man is a strong predictor of being a murderer. But most men are not murderers, so any man picked at random is unlikely to kill anyone. No man would expect to be convicted of murder without evidence that he intentionally killed somebody.



SHUTTERSTOCK

CRIMINAL ISSUE

Though we might expect that criminal courts treat each of us as individuals, algorithms are already used to predict who will commit a crime in future, or where, or who is at high risk of reoffending. This is an extension of what police officers and judges have always done, trying to prevent crime before it happens, or to keep offenders out of jail if they're unlikely to reoffend. In practice, though, it is very difficult to separate these predictions from the pitfalls described above: assuming the future looks like the past, and that what is true of a population is automatically true of an individual.

Prof Jeffrey Brantingham, from the University of California, Los Angeles, developed PredPol software to predict the locations of future crimes, based on models that forecast earthquakes. As it used data based on past reports of crime, it tended to send police back to the same communities, to find more crime and make more arrests. Widely used in the US and UK, it's now being abandoned by some police forces because of doubts about effectiveness as well as fairness.

Other algorithms assign risk scores to individuals to help judges or parole boards decide how likely they are to reoffend. They are based on comparing data on that individual with past populations, and have been challenged in the US courts for their lack of transparency, and for judging one person based on what others have done in the past. One risk score algorithm, called COMPAS, was found by investigative journalists at ProPublica to be more likely to wrongly assign black offenders as high risk, and white offenders as low risk. In July 2020, 10 US mathematicians wrote an open letter calling on their colleagues to stop working on such algorithms, because the outcomes were racist.

"The trouble with algorithms is not usually the maths. Most of the time, it's what the humans have designed them to do"

Prof Jeffrey Brantingham (blue shirt) developed the PredPol software to help predict future crimes, using data based on previous reports

But if the justice system is getting more cautious about using algorithms to make life-changing decisions, others are embracing them.

Employers inundated with job applications are turning to algorithms to filter out unsuitable applicants, based on how they compare with current employees. This has backfired – Amazon's algorithm, for example, was found to be using a correlation between being a successful current employee and being male, and had to be withdrawn.

Other employers claim that automating the first stage of the hiring process has widened their pool of new entrants. Unilever ditched recruitment fairs at a handful of top universities for online recruitment, where even video interviews were assessed by algorithms before a human saw any candidates. But critics point out that applicants with disabilities, or for whom English isn't their first language, may be penalised by algorithms assessing their body language or voice. And algorithms can be gamed. Some recruiters try to make their ads more appealing to women, by using software to make the language of the ad less 'masculine'. Using the same software, an applicant could make their job application sound more masculine – to an algorithm trained on a largely male workforce.

It's often claimed that algorithms can escape human bias and prejudice, if we design them for fairness instead of unfairness. It's true that writing a program can force us to decide what we mean by 'fair'. Is it more fair to give exam results that assume your school's past results are the best predictor of your own attainment, or to give you the grade your teacher predicted? The first will look closer to previous years' grades, the second gives each individual the benefit of being judged personally. But is that fair on students in better schools, whose teachers were less likely to over-predict?

LIFE'S UNFAIR

In an unfair world, it's a mathematical impossibility to create a fair algorithm. The company that designed the COMPAS algorithm defended its fairness, pointing out that neither race nor proxies for race were used as data. Instead, they blamed the disparity between the black and white populations. In the past, a black offender was more likely to be arrested for another offence. This made 'false positives' – wrongly assigned high risk scores – more likely in groups that looked, to the algorithm, like previous offenders.

Although the algorithm was blind to the race of the person being assessed, many of the inputs on which it based the risk score would not be found equally in different populations. Details like family or employment history, knowing other offenders, and even attitudes to questions on social opportunity, will differ for people with different experiences of the justice system, and of life generally.

Treating each individual equally gave unequal results on a population scale. To give equal results by population groups would mean adjusting individuals according to race, which is arguably just as unfair in a justice system which should be judging each individual on their own record and character. Whenever a person is judged on the basis of what others like them have done in the past, it's important to ask in what sense the others are 'like them'.

The advantage of using algorithms is that, if they are transparent, they force the institutions using them to be explicit about their assumptions and goals. In the Ofqual case, the goal was to make the overall distribution resemble previous years, and the assumptions included 'your school's previous performance is a better guide to your future performance than your own grades'. The trouble with algorithms is not usually the maths. Most of the time, it's what the humans have designed them to do. SF

by **TIMANDRA HARKNESS**
Timandra is a writer and broadcaster, specialising in data and statistics. She presents FutureProofing *on BBC Radio 4.*

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OUR EXPERTS

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Chemistry expert and science writer

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Environment and climate expert

ABIGAIL BEALL
Science and space writer

MARCUS CHOWN
Cosmology expert and science writer

DR ALASTAIR GUNN
Astronomer and astrophysicist

DR JEREMY ROSSMAN
Virology and disease expert

BEN HOLDER
Science writer, TV producer

DR CHRISTIAN JARRETT
Neuroscientist and psychologist

DR NISH MANEK
Medical expert and GP trainee

DR HELEN PILCHER
Biologist and science writer

DR BRENNA HASSETT
Archaeologist and anthropologist

LUIS VILLAZON
Science and technology writer

ILLUSTRATION: DANIEL BRIGHT

YASMIN HAYES (AGED 14), LONDON

WHY DO WE HAVE FAVOURITE COLOURS?

One possible explanation is that we've evolved to prefer colours that our ancient ancestors associated with survival, safety and health. Among adults, bluish hues tend to be more popular than yellowish brown ones, which might be because blue is associated with water and clear skies, while yellows and browns convey illness, human waste, and decay. Consistent with this evolutionary idea is that, already by just a few months of age, babies are picky about colours, preferring to gaze at brighter colours like blue and red rather than duller ones such as brown.

However, our life experiences and the culture we grow up in are also likely to play a large role in our colour preferences. There's evidence, for example, that our emotional reactions to objects and symbols can sway our preferences – the colour of our favourite football team, for instance, or a favourite piece of clothing. We might also like certain colours because of their emotional connotations. Yellow, for example, is often seen as a 'happy' colour, while darker colours can be more mellow and reflective.

There are also associations between colour preferences and gender, especially among children. For instance, already by the age of 2.5 years, girls in Western cultures seem to have a preference for pink objects, while boys tend to avoid pink. The roots of these gender differences are complex (likely reflecting a mix of biological and cultural factors) and are still being debated.

So there are a lot of factors at play, and there's unlikely to be a single explanation for why we like the colours we do. ***CJ***

DEAR DOCTOR...

DELICATE ISSUES DEALT WITH BY *SCIENCE FOCUS* EXPERTS

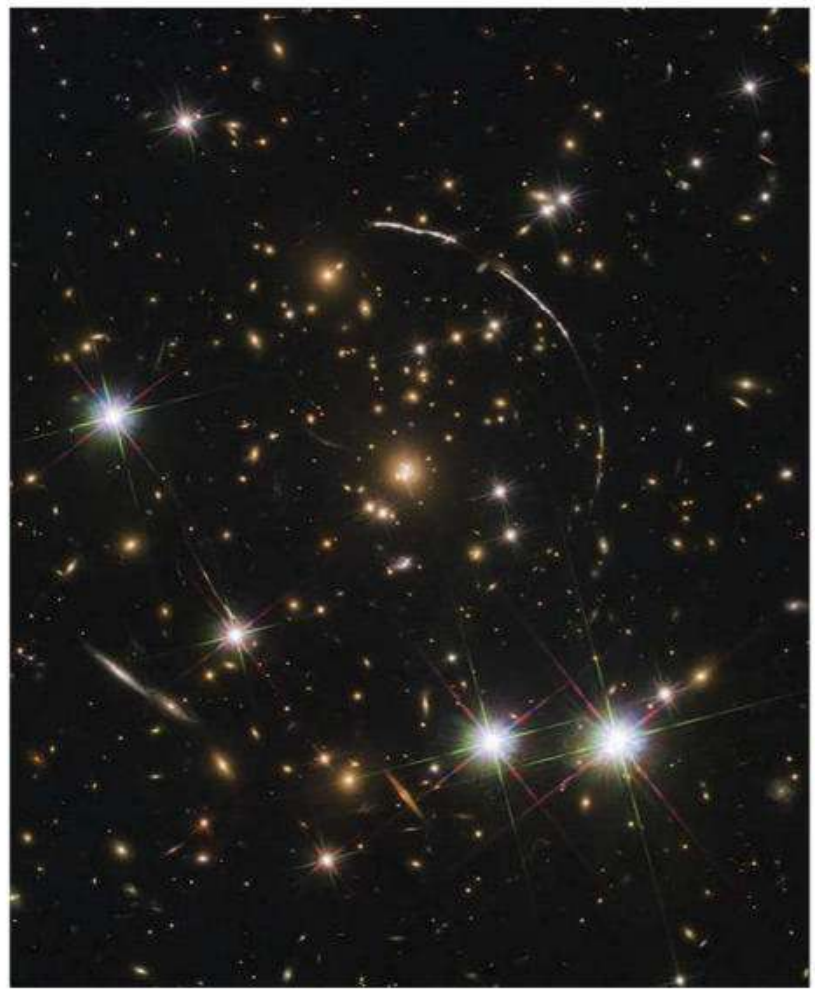
I'VE BEEN BLOCKED UP FOR DAYS AND I'M CONSIDERING TAKING A LAXATIVE. HOW DO THEY ACTUALLY WORK?

There are four main types of laxative, so it depends which one you take. 'Bulk-forming' laxatives (e.g. methylcellulose or ispaghula husk) are usually the first to be recommended. These contain fibre, which absorbs water and makes the poo larger. This stretches the bowel wall, which stimulates it to contract and move the poo along. The increased water content also makes the poo softer, so it's easier to pass.

If that doesn't work, you might try an 'osmotic' laxative (e.g. lactulose or polyethylene glycol), which work via the process of osmosis, where water moves from a high water concentration to a low one. These laxatives contain molecules such as sugars and salts that lower the water concentration in the bowel, causing water to enter and soften the poo. There are also 'poo-softening' laxatives (e.g. arachis oil, docusate sodium), which work by reducing the poo's surface tension so that more water can seep in.

Finally, if you're still constipated, you might need a 'stimulant' laxative (e.g. senna, bisacodyl). These work directly on the nerves that control the muscles in the bowel wall, causing the bowel to contract. These laxatives work faster than the others – within about 6 to 12 hours.

Talk to your pharmacist (or GP) if a certain type of laxative isn't working for you, and hopefully one of them will do the trick! ***NM***



COLIN AND ANN DOVE

HOW DO WE CALCULATE DISTANCES TO OTHER GALAXIES?

There are a few different methods, but one of the most common is the 'standard candle' method. This relies on the fact that if we know how bright an object in space really is (its 'intrinsic' brightness), then we can estimate its distance from how bright it appears to us from Earth (its 'apparent' brightness). A 'Cepheid variable' is one type of standard candle. Cepheid variables are a type of star that have a consistent relationship between their intrinsic brightness and how fast they pulsate – so you can watch one, and if it pulsates at x speed, you know its intrinsic brightness is y. Measuring the intrinsic brightness of a Cepheid variable, or other kinds of standard candles such as supernovae, allows astronomers to calculate the distance to the standard candle's home galaxy.

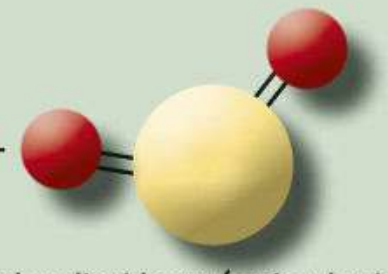
For the most distant galaxies, standard candles are too faint to be useful, so astronomers often use the 'Hubble-Lemaître' law, which shows that the further a galaxy is from Earth, the faster it is moving away from us. This is just a consequence of the fact that the Universe is expanding. Astronomers first measure the speed of the galaxy by analysing the shift in the galaxy's light towards the red end of its light spectrum (its 'redshift'), and once its speed is known, they can work out its distance. ***AG***

NASA/HUBBLE SPACE TELESCOPE, GETTY IMAGES X4, ALAN HENDERSON/COVER IMAGES ILLUSTRATIONS: DANIEL BRIGHT

WHAT CONNECTS

VOLCANOES AND FRANKENSTEIN?

1. The most powerful volcanic eruption in human history was that of Mount Tambora in 1815. Located on the island of Sumbawa in modern-day Indonesia, it ejected around 150 cubic kilometres of ash and debris. Tambora's caldera is pictured above.



2. Sulphur dioxide gas (molecule pictured above) ejected by Tambora formed small, sulphur-rich particles in the atmosphere, which reflected solar radiation back into space and reduced global temperatures.

3. In Europe and the US, 1816 became known as the 'year without a summer' because of the cold, wet conditions. In Switzerland, Lord Byron (pictured) spent his summer at a villa on the banks of Lake Geneva.

4. Stuck inside because of the rain, he challenged his holiday companions to write a horror story. One of these companions was Mary Shelley (pictured), who came up with the idea that would become her 1818 novel *Frankenstein*.

NATURE'S WEIRDEST CREATURES

THE MAD HATTERPILLAR

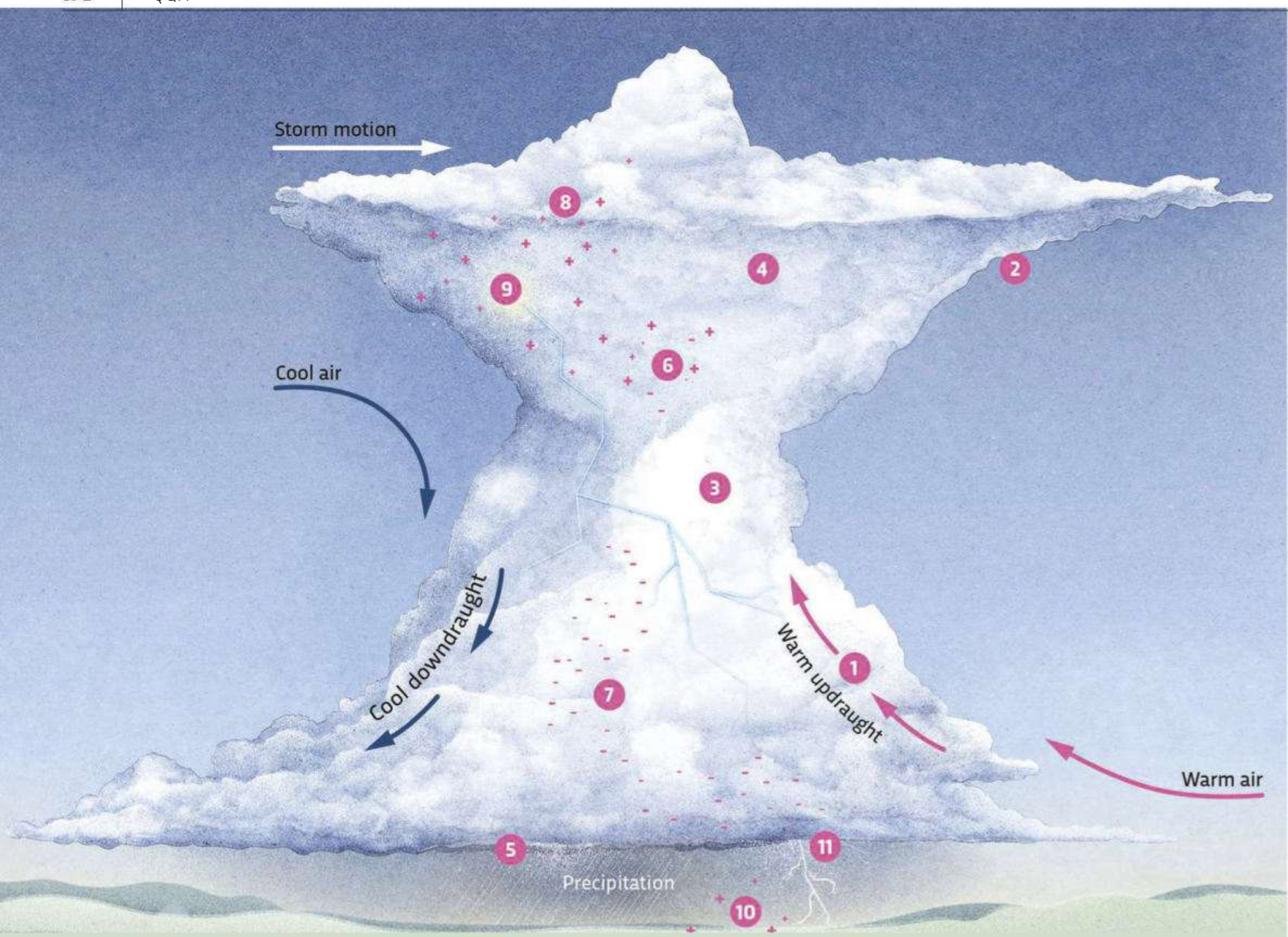
It's that age-old dilemma. Where to keep all those moulted heads that you've grown out of? On the mantelpiece? In the wardrobe? Or on top of your head, like the world's most outrageous fascinator? If you're a caterpillar of the *Uraba lugens* moth, you'll no doubt plump for the latter. Nicknamed 'the mad hatterpillar', after the Mad Hatter from Lewis Carroll's *Alice's Adventures in Wonderland*, this caterpillar lives in New Zealand and Australia, where it is a serious pest of eucalyptus trees. It munches eucalyptus leaves down to the veins – a talent which has also earned it the name of 'gum-leaf skeletoniser' (eucalyptus trees are commonly known as gum trees).

Just like all caterpillars, *U. lugens* must regularly shed its exoskeleton in order to grow. But unlike other larvae, it doesn't discard the empty head casings. After the fourth moult, it starts stacking the increasingly large structures on top of its noggin to form what has to be the world's most bizarre 'hat'. Scientists think the unlikely edifice may be anchored by a crown of sticky hairs. Caterpillars use the protruding headgear to swat predators, such as stink bugs, away. How's that for an excellent hat trick? ***HP***

ANGUS THORP, STAFFORDSHIRE

WHY DO PEOPLE GRUNT WITH EFFORT?

When you exert yourself, it helps to stiffen your torso to provide a rigid anchor point for the muscles of your arms and legs. This works best if you hold your breath and tense your abdominal muscles, compressing the air in your lungs. As you ease off and breathe out again, the air is forced out of your throat, still partially clamped shut, and this creates the grunting sound. A 2014 study found that grunting gives tennis players stronger serves. ***LV***



HOW DO THUNDERSTORMS FORM?

All thunderstorms begin with moisture and rising warm air. This typically occurs on a summer's day when the longer hours of sunshine have heated the ground. The warm, moist air immediately above the ground is less dense than the cooler, drier air above, causing it to rise. As it lifts, the water vapour it contains begins to cool and condense into water droplets, and a thundercloud begins to form. ***AFC***

1 Heat is released as the water vapour condenses, giving the rising air a boost and creating a powerful updraught.

2 Within about 30 minutes, a towering thundercloud (cumulonimbus) builds up, reaching heights of up to 10 kilometres.

3 As water vapour condenses inside the cloud, the water droplets merge and grow.

4 Ice particles also form and combine in the freezing, upper reaches of the cloud.

5 Once the water droplets and ice particles are heavy enough, they fall as rain or hail, generating a cool downdraught in their wake.

6 Collisions between ice crystals and water droplets inside the cloud knock electrons off the water droplets and the lighter ice crystals, and transfer them to the bigger ice particles.

7 Heavier, negatively charged particles sink.

8 Lighter, positively charged particles rise.

9 The difference in charge between the top and bottom of the cloud creates a voltage that can discharge in 'intra-cloud' lightning.

10 The negatively charged cloud base also repels electrons on the ground, creating a positive charge there.

11 This voltage can discharge in 'cloud-to-ground' lightning. The rapid heating and expansion of the surrounding air causes thunder.

GETTY IMAGES X2 ILLUSTRATION: DANIEL BRIGHT

PAD SCANLON, LONDON

COULD AN APE PLAY ROCK, PAPER, SCISSORS?

In 2017, researchers in Japan and China revealed that they'd taught five chimps the rudiments of rock, paper, scissors by showing them pairs of gestures on a touchscreen, and then giving them food treats when they picked the winning one. The chimps first learned that paper beats rock, then that rock beats scissors and finally that scissors beats paper. Later, when the chimps were shown paired pictures randomly, they picked the winning sign 9 times out of 10, putting them on a par with a four-year-old child. The chimps weren't making the gestures themselves, though, so we don't know if they'd have the dexterity to actually play it. ***HP***

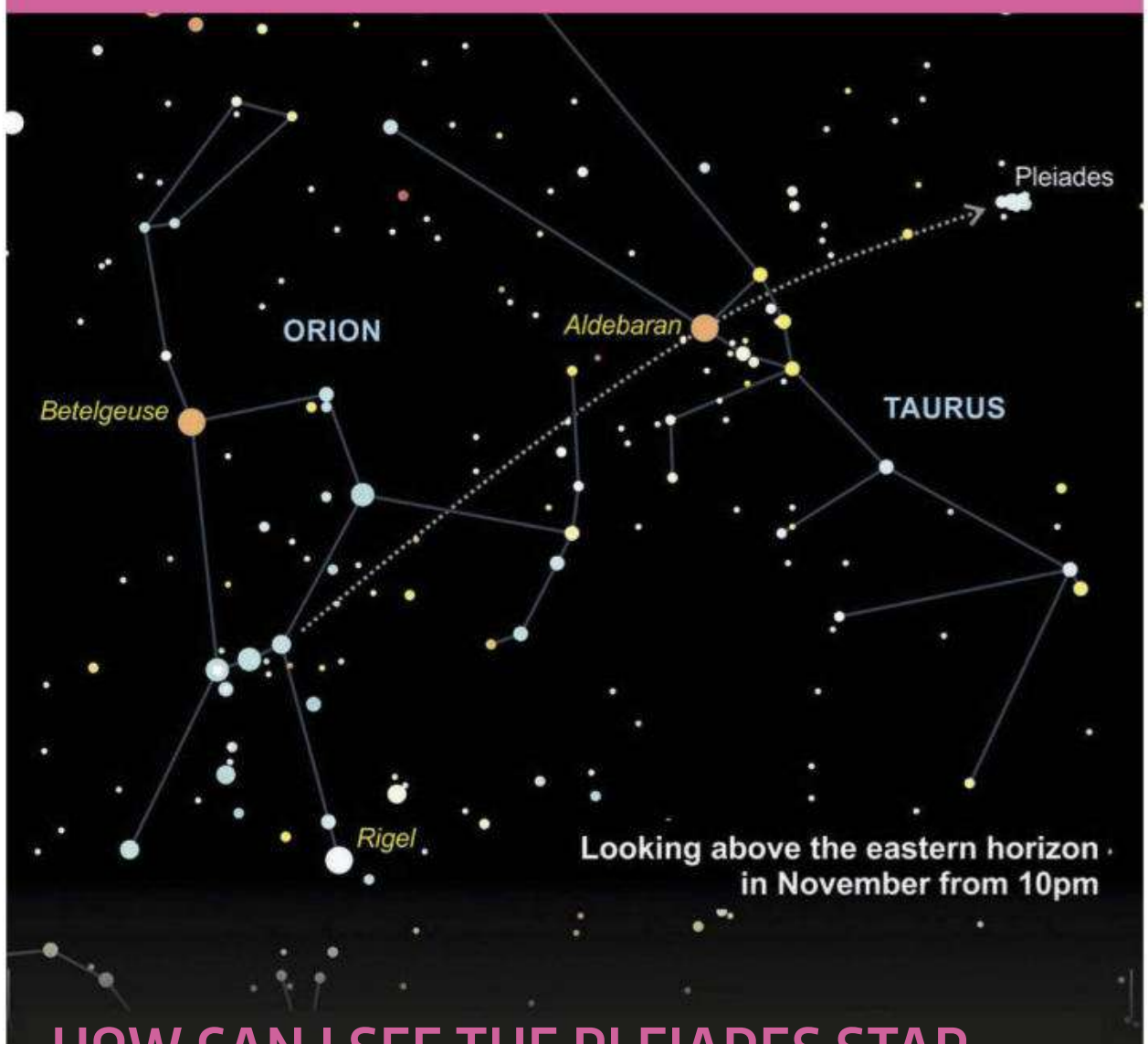
CROWDSCIENCE

Every week on BBC World Service, *CrowdScience* answers listeners' questions on life, Earth and the Universe. Tune in every Friday evening on BBC World Service, or catch up online at **bbcworldservice.com/crowdscience**

WHEN DID HUMANS FIRST START WEARING CLOTHES?

To expand into the cold hinterlands of Europe and Asia, our ancestors needed to keep warm. The earliest possible evidence for clothing in ancient humans is stone tools found at archaeological sites like Gran Dolina in the Spanish Atapuerca Mountains (associated with *Homo antecessor* and dated to around 780,000 years ago), or in Schöningen in Germany (*Homo heidelbergensis*, around 400,000 years ago), which may have been used to prepare animal hides. We see clearer evidence from the Neanderthals, who lived as far back as 400,000 years ago: the pattern of musculature on Neanderthal arms suggests that they habitually carried out tasks like hide preparation. Despite having bodies that were more cold-adapted than ours, a 2012 study estimated that Neanderthals may have needed to cover up to 80 per cent of their bodies to survive the harsh winters. In modern humans, (*Homo sapiens*), the adoption of clothing may have left its traces on some hangers-on: a 2011 study suggested that clothing lice began to genetically diverge from human head lice around 170,000 years ago, proposing a date for when we started to wear clothes. During winter, we probably needed to cover as much as 90 per cent of the body, which may be why we developed more modern-looking clothing than the fur cloaks that Neanderthals are suggested to have worn. By around 40,000 years ago, we were using needles and awls, made out of bone and stone, to create sewn, fitted clothes to keep us warm. ***BHa***

ASTRONOMY FOR BEGINNERS



HOW CAN I SEE THE PLEIADES STAR CLUSTER?

WHEN: OCTOBER TO APRIL

The Pleiades, or Seven Sisters, is the most well-known star cluster in the night sky. It's what's known as an 'open cluster', which is a group of stars that form from the same huge cloud of dust and gas. As the cloud collapses under gravity, temperatures rise and stars begin to take shape, becoming loosely bound by their mutual gravitational attraction.

The Pleiades contains some 3,000 stars, all less than 100 million years old, making them mere babies compared to our Sun's 4.6 billion years. The cluster's name possibly comes from the Ancient Greek word *plein*, meaning 'to sail', because the first appearance of the cluster in the dawn sky each year heralded the start of the sailing season. It's thought that the name Pleiades was later used in Greek mythology for the seven daughters of the titan Atlas and the sea nymph Pleione.

In the night sky, the Pleiades sits within the constellation of Taurus. It's actually possible to see up to 14 of the stars with the naked eye in areas with no light pollution. You can see the Pleiades between October and April, but the best month to look for it is November, when it can be seen for the entire night.

To find the Pleiades, first locate the three stars in Orion's Belt. During November, look above the eastern horizon from around 10pm. Draw an imaginary line going through the belt from left to right, and continue this line through Orion's bow. This will direct you to the brightest star in Taurus: Aldebaran. Past Aldebaran, in the same direction, is the Pleiades. It's easily recognisable, because the positions of its five brightest stars make it look like a tiny version of the Plough. Once you've found it, grab a pair of binoculars if you have one, and take a closer look to reveal more of the cluster's stars. ***AB***

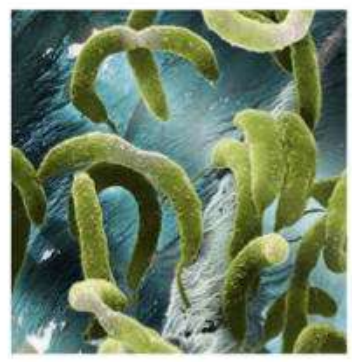
ANNA ZAMOJSKA, LONDON

WHY DO WE GET A RUNNY NOSE AFTER WE CRY?

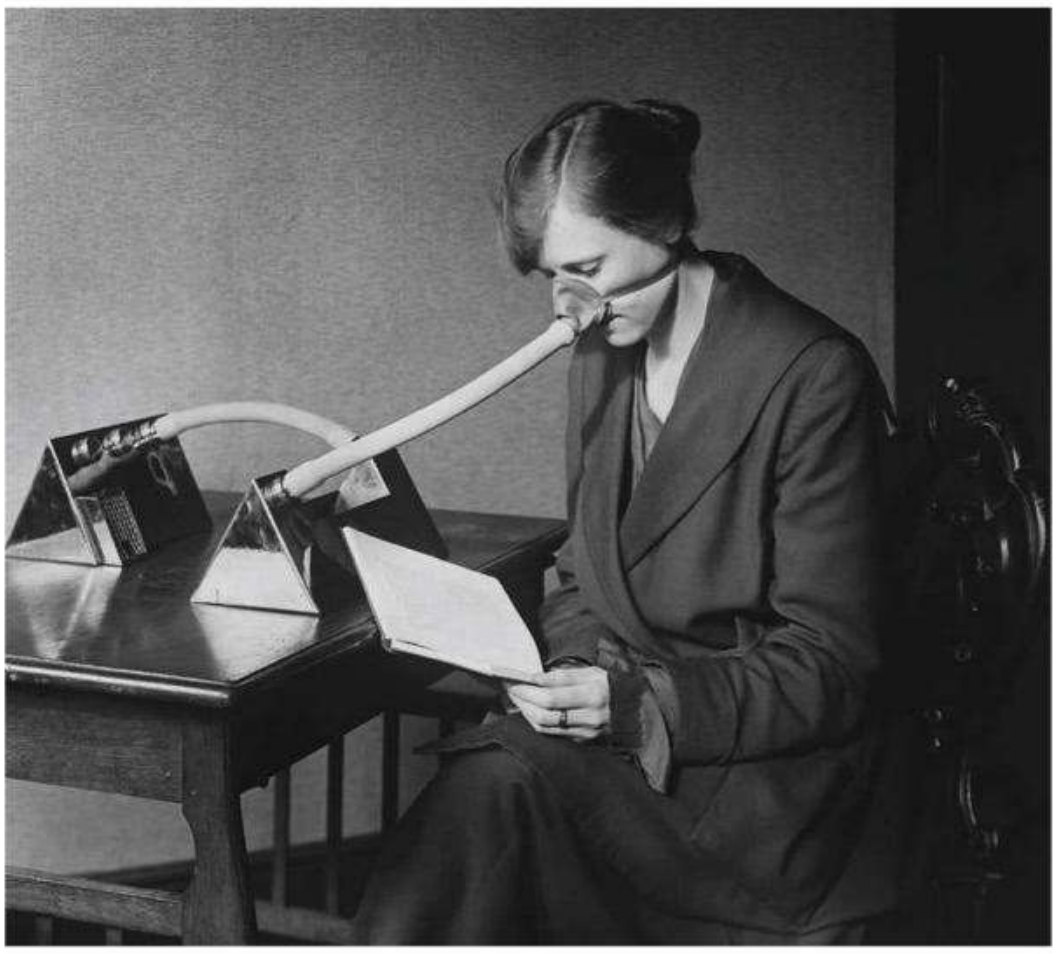
A runny nose is a side effect of many things: a cold wind, a hot curry, bonfire smoke, and a good cry. The common denominator with all these is that they make your eyes water. Your eyes have tiny drain holes, called lacrimal puncta, located in the inner corners of your upper and lower eyelids. These connect to your nose via channels called the 'lacrimal canaliculi', so any tears that don't run down your face will dribble into your nose. ***LV***

JOHN WILLIAMS

WHAT IS THE STRONGEST NATURALLY OCCURRING ADHESIVE?



The unofficial record is held by a harmless bacterium that lives in all sorts of freshwater environments, including tap water. *Caulobacter crescentus* (pictured left) attaches to underwater surfaces via a stalk-like structure that has an ultra-sticky adhesive at its tip, made from the sugars glucose, mannose and xylose. According to measurements by US researchers, just one square centimetre of this natural glue could stick a 680kg weight (or a large cow) to a wet surface. ***ED***



TAMSIN NICHOLSON, WARWICKSHIRE

WOULD SPANISH FLU BE AS DEADLY IF IT OCCURRED TODAY?

The 1918-1920 flu pandemic, often called 'Spanish flu', infected around 500 million people worldwide, killing as many as 50 million. In comparison, the coronavirus SARS-CoV-2 has, at the time of writing, killed over 900,000 from almost 30 million confirmed cases. The influenza virus that caused Spanish flu eventually mutated into a less dangerous strain, but if an outbreak of the original Spanish flu strain happened today, it'd likely be far less deadly than a century ago.

When Spanish flu struck in 1918, scientists thought it was transmitted by bacteria, and it wasn't until 1931 that the influenza virus was discovered. Today, we have a good understanding of flu viruses and how they spread, and we can develop and make vaccines for new flu strains in a matter of months. Also, in the 1918-1920 pandemic, an estimated 95 per cent of fatalities were caused by bacterial pneumonia (flu infections make it easier for certain bacteria to grow in the lungs). Today, most of these cases could be treated with antibiotics, and we also have the added resource of mechanical ventilators, for the more severe cases. ***JR***

QUESTION OF THE MONTH

KAMILA MAGOMEDOVA (AGED 13)

DO WET SHEEP SHRINK?

Wool fibres aren't completely smooth – they have microscopic scales that interlock with those on adjacent fibres when you wash them, pulling them together like a ratchet and causing them to contract. That's why your woolly jumper shrinks in the wash. Luckily, sheep secrete an oily substance from their skin called lanolin, which lubricates the wool and prevents the fibres from tangling when they get wet, so their fleece stays nice and full in the rain. When woolly jumpers shrink, they don't stretch again when they dry out. So a shrunken sheep would be shrunken forever! ***LV***

WINNER

Kamila wins a **Turing Tumble,** worth £56. Turing Tumble is a new game where players build mechanical marble-powered computers, to solve logic puzzles. It's fun to play and helps you discover how computers work. **turingtumble.com**

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM** OR TWEET US **@SCIENCEFOCUSQA**

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THE EXPLAINER

WHY IS THERE A HURRICANE SEASON?

WHAT CAUSES HURRICANES?

Hurricanes are some of the most powerful storms on Earth, drawing their energy from warm tropical waters in the Atlantic or northeastern Pacific. In other parts of the world, these swirling storms are known as typhoons (in the northwestern Pacific) or cyclones (South Pacific and Indian Ocean).

These storms form above ocean waters when warm, moist air rises. This draws in more humid air from surrounding areas, and as the air rushes in, the Coriolis effect (created by the Earth's spin) causes it to follow a curved path, leading the developing storm to spin anticlockwise in the northern hemisphere. As the rising air cools, the moisture condenses out and forms rain clouds.

As long as there's sufficient heat from the oceans, the storm continues to grow, and it may eventually be intense enough to produce the 119km/h winds that officially define a hurricane. As the hurricane rotates faster, a calm 'eye' of low air pressure forms at its centre, surrounded by the strongest winds. The Saffir-Simpson hurricane wind scale classifies hurricanes from 1 to 5 based on wind speed, with category 5 hurricanes fostering winds of 250km/h and above.

Most hurricanes in the North Atlantic form off the western coast of Africa, and are carried to North America, the Caribbean, and the Gulf of Mexico by the prevailing easterly winds. Once they make landfall, they weaken and dissipate, but not before unleashing devastatingly strong winds and heavy rains on anything in their path, as well as causing storm surges (an abnormal rise in sea level). An average of six hurricanes are produced in the Atlantic every year, but the 2020 season has been exceptionally active, with eight recorded as of late September.

WHAT CONDITIONS DO HURRICANES NEED TO FORM?

In the North Atlantic, hurricane season runs from early June to late November. Hurricanes are fuelled by heat, and only form when upper ocean waters hit 26°C and above, so they always originate in tropical and subtropical regions. The ocean gradually warms over the summer months, reaching the optimal temperatures for hurricane formation in August or September. In summer, the vertical wind shear (abrupt changes in wind speed and direction with altitude) weakens over the Atlantic. Wind shear can disrupt the vertical flow of warm humid air and cause storms to break down; without it, there' s more chance of hurricanes forming.

GETTY IMAGES X4, NASA

IS CLIMATE CHANGE AFFECTING THE HURRICANE SEASON?

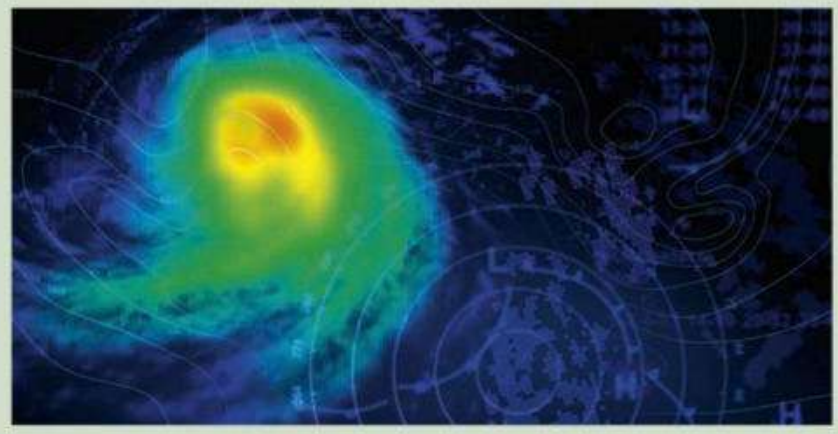
Hurricanes are closely linked to warm oceans, so it seems likely that rising temperatures caused by climate change will affect hurricane formation. The UN's Intergovernmental Panel on Climate Change (IPCC) predicts that, while a warming climate may not affect the number of hurricanes we experience in each season, it is likely to increase their intensity. By 2100, we can expect around 30 per cent more hurricanes and other tropical cyclones to reach category 4 or 5.

Increased moisture in the atmosphere linked to climate change is also expected to generate hurricanes with 10 per cent more rainfall. Rising sea levels could also worsen the damage that hurricanes inflict by making coastal areas more vulnerable to flooding.

The interactions between climate change and the many factors that affect hurricane formation are complex, so it's difficult to attribute any one hurricane directly to climate change.

WHY DOESN'T THE UK EXPERIENCE HURRICANES?

Although hurricanes can travel vast distances, they rely on warm ocean water to sustain them – a large mass of cold water can stop them in their tracks. Located far from the tropics, and with no hurricane-friendly warm waters, the UK doesn't experience true hurricanes, but it does occasionally receive the remnants of them. These 'ex-hurricanes' morph as they travel from the tropical Atlantic to mid-latitudes, deriving their energy from the converging of warm tropical air with cold polar air, and often causing high winds and heavy rainfall not dissimilar to hurricanes. A recent ex-hurricane was Ophelia in October 2017, which battered Ireland with record-breaking gusts of up to 190km/h.



HOW ARE HURRICANES PREDICTED?

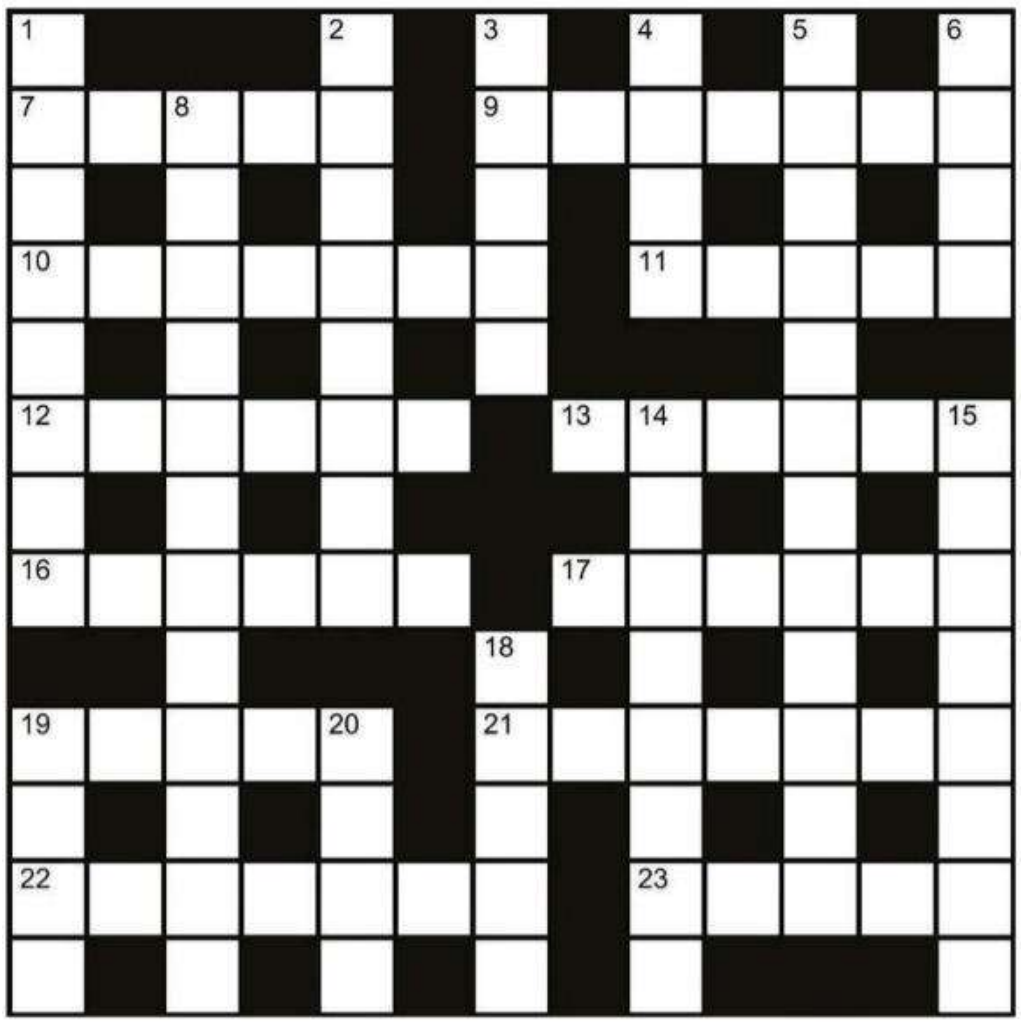
Hurricane prediction has two components: predicting the intensity of hurricanes, and forecasting where they're likely to make landfall. Both are complex tasks, but intensity forecasting is the most challenging, as it requires an understanding of relatively small-scale phenomena, such as the atmospheric circulation within a hurricane's eye.

Recent decades have seen huge improvements in our ability to predict where a hurricane will hit, thanks to improved satellite observations and more powerful supercomputers. Meteorologists build computer models that use data on previous hurricanes and current weather conditions, along with equations describing how the ocean and atmosphere behave, to calculate a hurricane's likely track. In the 1980s, track forecasts were off by an average of 650km – nowadays this has dropped to 185km.

by ALEXANDRA FRANKLIN-CHEUNG
Alexandra is a climate and environment journalist.

CROSSWORD

GIVE YOUR BRAIN A WORKOUT



ACROSS

7 Stone designs are captivating doctor (5)
9 Sing about oil mixed with medium metal (7)
10 Also free to acquire old robot (7)
11 Trace of wheat, say (5)
12 Scottish team, or maybe Cornish (6)
13 Sponsor has right to devotion (6)
16 Mean to study broken toe (6)
17 Pass law around start of year (6)
19 Small amount of money for seafood (5)
21 Note a great deal – it's different around the vocal cords (7)
22 Warning device for hog moving north (7)
23 Shy and stupid to object to return (5)

DOWN

1 What's left, on the day, is fair (8)
2 Trains so curiously to be a criminal (8)
3 Cold skin gets rebuke (5)
4 Bullet for a garden pest (4)
5 Sets my brainy solution in base two (6,6)
6 Old chap from the country (4)
8 Shape tongue in meaningful gestures (4,8)
14 Our dates displayed in printed information (4-4)
15 Call team close to the action (8)
18 In the past, city was in pain (5)
19 Until now, hasn't finished some furniture (4)
20 Daughter gets exotic greeting in exotic ship (4)

ANSWERS

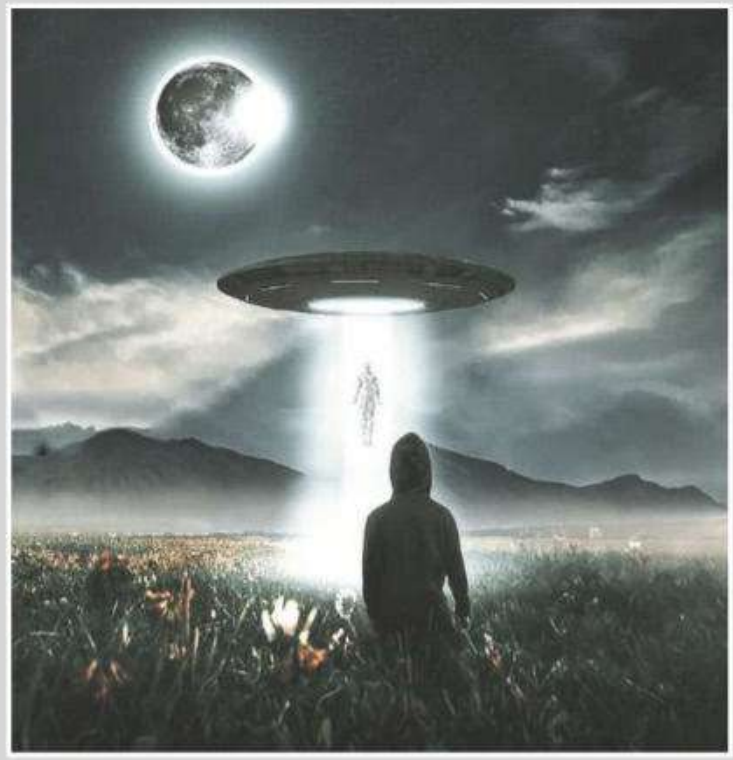
For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

GETTY IMAGES

NEXT ISSUE

WHY WE WANT TO BELIEVE

What is it about alien life that captures our imagination?



PLUS

WORLD'S LARGEST DIGITAL CAMERA

Inside the lab that's building a 3.2-gigapixel camera that will record the first motion picture of the Universe.

ASTRONOMY FOR BEGINNERS

How to spot the Gemini constellation.

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A SCIENTIST'S GUIDE TO LIFE

HOW TO STAY TOASTY

AS THE TEMPERATURE DROPS, AND OUR THOUGHTS TURN TO THERMAL VESTS, WE ASK PHYSIOLOGIST **DR JOHNERIC SMITH** HOW TO STAY WARM

STAYING WARM IS A BALANCE...

… between heat produced and heat lost. When we get cold, we often shiver because shivering generates heat. At the same time, blood flow is diverted away from the extremities, like the fingers and toes, to the torso. This helps protect vital organs, like the heart and lungs, and reduce heat loss to the surroundings.

SOME PEOPLE FEEL THE COLD MORE THAN OTHERS...

… even in the same environment. This is to do with size, fat and metabolism. Smaller people with less body fat lose more heat to their surroundings than bigger people with more fat. Bigger people may have more muscle mass, and are therefore able to produce more heat.

LAYERING IS CRITICAL.

It acts as insulation because it traps warm air close to the body. Layers are easy to put on and peel off, helping you react quickly to changes in temperature.

TAKE YOUR COAT OFF INDOORS.

If you wear a coat indoors and get really warm, blood gets diverted to the skin to help cool you down. If you then go outside, the cold air will sap this heat from your skin and leave you feeling colder than you would do otherwise.

EXPENSIVE JACKETS AREN'T NECESSARILY BETTER.

The price is often more to do with the weight and warranty than warmth. When Edmund Hillary climbed Everest, he wore wool, which is warm but heavy. Expensive jackets are often lighter, but the trick is to look for one that traps heat next to the body well. I don't care if a jacket is synthetic or down, as long as it does this.

THE HEAD DOESN'T LOSE HEAT MORE RAPIDLY THAN THE REST OF THE BODY.

If you wore a hat and nothing else, you'd still lose heat from everywhere else! That said, it's the one area we often leave uncovered in the cold, so wearing a hat is still a good idea.

GET ACTIVE... BUT NOT TOO ACTIVE.

Physical activity gets your muscles working and generates heat, but it can be a double-edged sword. Too much exercise makes you sweat, which cools you down as it evaporates. So, you could end up feeling colder than before you started exercising.

HAVE A SNACK.

When food is broken down, it generates energy and heat. If I'm camping, I'll often have a snack before I go to bed – something that's high in fat and protein, like a chocolate bar with nuts, will require the body to work harder to digest it.

YOU CAN BECOME ACCLIMATISED TO THE COLD.

Fishermen who work in really cold places sometimes develop a reflex called the 'hunting reaction' where blood is repeatedly shunted to and from their hands. It means they can retain dexterity in their fingers, and fillet their fish without getting frostbite. We also see adaptation when we give athletes ice baths. At the beginning, they find it hard to tolerate, but it becomes easier with time. SF

DR JOHNERIC SMITH

JohnEric is an associate professor of exercise physiology at Mississippi State University.

Interviewed by Dr Helen Pilcher.

NEED TO KNOW...

1

Wear lots of layers – they'll trap heat to help you stay snug.

2

You don't lose heat disproportionately through your head, but you should still wear a hat.

3

Your mum was right! Take your coat off when you get inside.

ILLUSTRATION: CAT FINNIE

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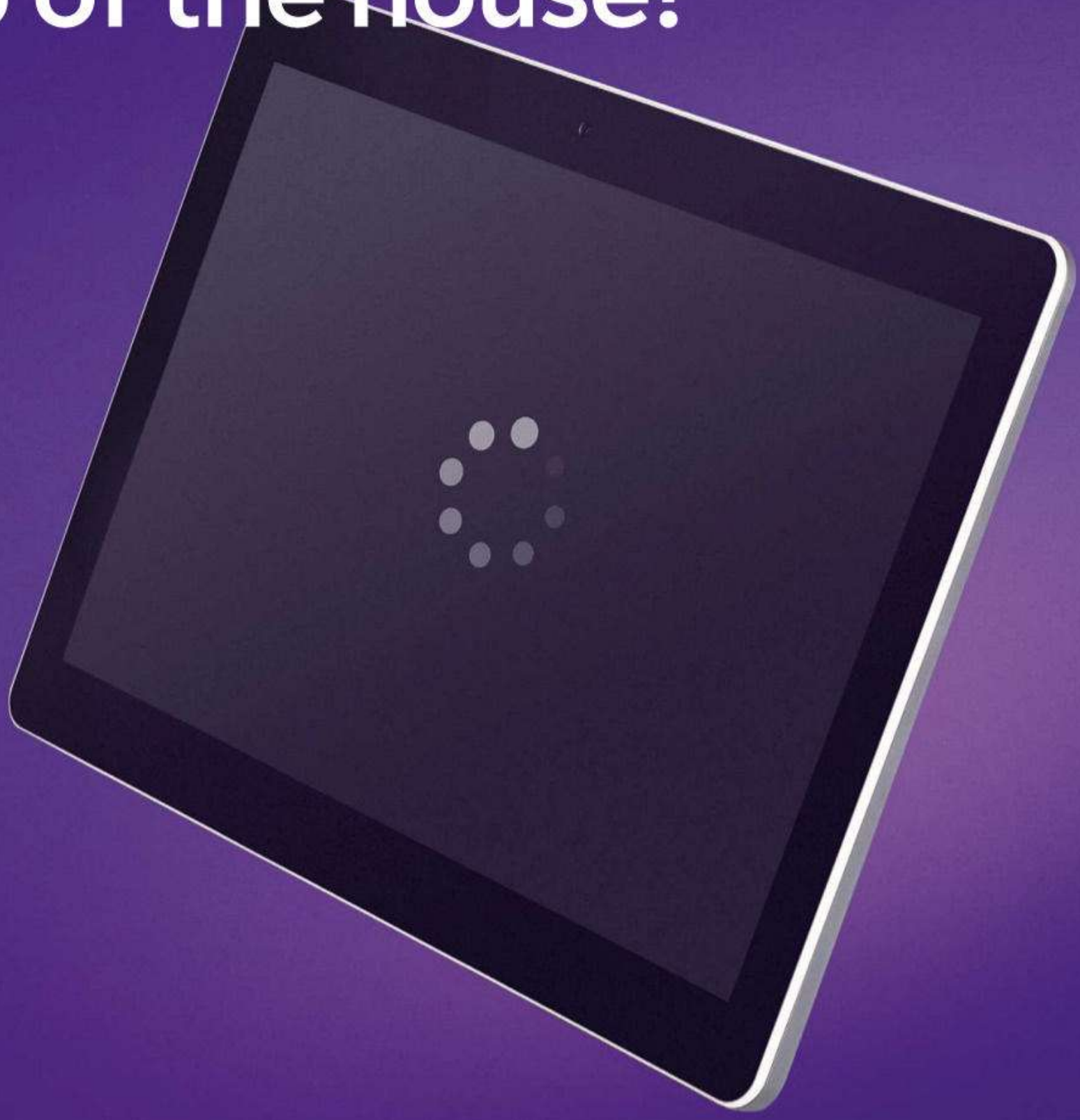

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